UNEVEN ARM LOAD AND RHYTHMIC ARM COORDINATION

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Submitted in partial fulfillment of the requirements
for the Master of Science degree
in the School of Health, Physical Education and Recreation,
Indiana University

2011

May 5, 2011

Accepted by the Graduate Faculty, Indiana University, in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

Uneven Arm Load and Rhythmic Arm Coordination

Bilateral limb coordination has been examined for different types of locomotion from basic movements, such as walking, to movements that require more coordination, such as those performed while swimming. Although many studies have examined the effects of coordination while walking, examining the effects of coordination while swimming has been difficult to do even though both are bilateral rhythmic movements. Changes or differences in the metabolic cost during movements in air cause relatively small, but important, differences in economy and/or efficiency. These differences may be on the order of a percentage or two. However, non-coordinated movements in the water during propulsion can cause differences in economy and/or efficiency of 50 to 100 or more percent. The purpose of the current study was to investigate the metabolic cost of arm coordination occurring with a change in load distribution between two arms.

Eleven competitive swimmers (men age 21.4 ± 4.4 yrs) performed a discontinuous maximal aerobic capacity test and an arm coordination test (AT) on a modified pulley weight stack, which is similar to a swim bench. The AT consisted of three randomized trials with workloads based on the subject's peak oxygen consumption (VO_{2Peak}). The three trials consisted of a workload corresponding to 50% of workload at the subject's VO_{2Peak} (WL1), a workload corresponding 65% of workload at VO_{2Peak} (WL2), and a workload corresponding 80% of workload at VO_{2Peak} (WL3). Within each trial there were three randomized arm loading profiles: even arm load distribution (EL) and two uneven arm load distributions, right arm loading (RL) and left arm loading (LL). Subjects were instructed to mimic a front crawl pull throughout the 5-minute exercise bouts. Arm coordination was determined using the

index of coordination (IdC) (Chollet, 2001) which expressed the percentage of the total stroke when no propulsive forces were made by the subject. Oxygen consumption (VO_2) and heart rate were measured in minute and 30-second intervals respectively.

The mean VO_2 of the subjects significantly increased from WL1 to WL2 and WL3 ($p < 0.05$); however, there were no significant differences in VO_2 within each trial. Mean IdC for both the left and right arms were not significantly different within each trial and between trials ($p > 0.05$). The mean stroke lengths of the right arm were not significantly different from the left arm, with the exception of the LL at WL2 (1.08±0.20 m, 0.98±0.11 m) ($p = 0.002$) and LL at WL3 (1.12±0.23 m, 1.00±0.09 m) ($p = 0.003$).

This was the first study to examine arm coordination on swimmers out of the water and to modify the workload placed on each arm. The results from the study suggest that the uneven load profiles did not have an effect on either the metabolic demand of the movement or the coordination of the arms while on the MPWS. Future research is needed to compare coordination patterns while swimming in and out of the water.

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CHAPTER 1

INTRODUCTION

Coordination of limbs has been examined for many different types of locomotion from basic movements such as walking to movements that require more coordination such as those performed while swimming. Central nervous system coordination is used to stabilize a movement, but of equal importance, it allows the movement to be produced at the lowest metabolic cost. Although many studies have examined the effects of coordination while walking, examining the effects of coordination while swimming has been difficult to do even though both are bilateral rhythmic movements. When walking, the right arm moves in synchronization with the left leg. However, in swimming the front crawl, the arms make a full 360-degree rotation while the legs follow a linear path. Interestingly, it has been shown that when swimmers are suspended in the air and asked to perform a swimming motion, the coordination pattern becomes similar to the coordination pattern of walking (Wannier, Bastiaanse, Colombo, & Dietz, 2001). Even though walking and swimming are two distinct modes of locomotion, similarities exist between their locomotion patterns. By examining the limbs that provide the primary forward propulsion, such as the legs while walking and the arms while swimming, similar rhythmic movements and coordination patterns become apparent between them. During walking, one leg provides propulsion while the other leg is recovering over the ground, and while swimming the front crawl, one arm provides propulsion while the other arm is recovering over the water.

Coordination of limbs can have an important impact on the metabolic cost of a movement. When given the option of choosing a pace at which to walk, animals and humans alike will select a pattern that minimizes the metabolic cost. This has been observed during other rhythmic movements (e.g. swimming) as well (Goodman, Riley, Mitra, & Turvey, 2000; Holt, Hamill, & Andres, 1990b, 1991; Holt, Jeng, Ratcliffe, & Hamill, 1995). For prolonged tasks, the individual who is using a metabolically unfavorable coordination pattern will expend more energy throughout the task than individuals who are completing the task with a metabolically optimal pattern. Changes or differences in the metabolic cost during movements in air cause relatively small, but important, differences in economy and/or efficiency. However, non-coordinated movements in the water during propulsion can cause significant differences in economy and/or efficiency. This study will evaluate changes in metabolic cost associated with bilateral arm coordination.

Statement of the Problem

The focus of this study will be to determine if imbalances in load distribution between two arms has an impact on the metabolic demand of a rhythmic arm movement. Identifying the response of the dynamics of coordination, such as relative phase, to an asymmetric arm load distribution is important to better understand bilateral coordination.

Purpose of the Study

This research will be conducted to investigate the metabolic cost of arm coordination occurring with a change in load distribution between two arms.

Justification for the Study

Although many studies have examined bilateral coordination between fingers or wrists under asymmetric conditions, there have been a limited number of studies that have been able to produce similar findings during locomotion. Coordination during locomotion must take additional factors into account. Factors, such as the center of mass of the moving limb or the effect of balancing, are reduced or eliminated with the finger or wrist protocols. Therefore, it might not be appropriate to relate these findings to bilateral coordination during locomotion. Nevertheless, Russell et al. (2010) were able to demonstrate a difference in the stride frequency of walking under asymmetric conditions similar to frequency differences observed during earlier studies on fingers and wrists. Unlike previous walking studies, the stride period was held constant and the asymmetry between the legs was increased through the attachment of 3 kg and 6 kg weights. As previously mentioned, the limbs that provide the primary forward propulsion in both walking and swimming produce similar rhythmic movements and coordination patterns. Thus, the current study will utilize the rhythmic motion that occurs while mimicking a front crawl swimming motion instead of walking on a treadmill to examine the effects an uneven arm load has on the coordination pattern and to examine the metabolic costs of an uneven rhythmic arm motion.

Delimitations

This study will be delimited to the following:

1. Eleven male students between the ages of 16 and 29 years old without a USA national swimming cut in the 50 yd, 50 m, 100 yd, or 100 m freestyle events.
2. A swim bench will be used to determine the arm coordination outside of the water.
3. Stroke end points used to determine coordination will be measured using tachometers attached to pulleys on each weight stack. The tachometers measure the length of the stroke as well as the speed of each stroke.
4. Expired gases during the exercise bouts will be measured to determine oxygen uptake.

5. This study will be conducted over a three month period between September and November, 2010.

Limitations

The results from this investigation will be interpreted considering the following limitations:

1. Variables other than the ones measured in the current study might have an impact on the metabolic cost while performing a swimming motion on the swim bench.
2. Propulsive forces of the legs during swimming, which could impact the coordination and metabolic cost while in the water, will not be accounted for in the current study.

Assumptions

The study was based upon the following assumptions:

1. The swim bench accurately mimics a front crawl swimming motion.
2. Subjects quickly become familiarized with the swim bench.
3. Subjects will perform at their optimal arm coordination.

Hypotheses

The study is designed to test the following hypotheses:

1. Oxygen consumption will increase with an increase in the load applied to each arm.
2. Subjects will perform the swimming motion at a lower metabolic cost under the evenly distributed load conditions as compared to the unevenly distributed loading conditions.
3. An even distribution of the load between the arms will result in the preservation of an catch up coordination pattern.

4. An uneven distribution of the load between the arms will result in a transition from an catch up coordination to a more stable opposition coordination pattern.

Definition of Terms

For consistency of interpretation, the following terms are defined:

Anti-phase Coordination. A comparison of two body segments oscillating, with respect to the midline, in a parallel movement. The movement is produced by simultaneously contracting antagonist muscle groups in both limbs (Kelso, 1984; Obhi, 2004).

Catch Up Coordination. An arm coordination pattern in swimming where there is a separation between the propulsive phases of the two arms (Chollet, Chalies, & Chatard, 2000).

Coordination. Behavior of two or more degrees of freedom in relation to each other to produce skilled activity (Schmidt, 1995).

Entry and Catch Phase. The time from when the hand enters the water until the first backward movement (Chollet, et al., 2000).

Heart Rate. The number of heart beats per minute (Brooks, 2005).

In-phase Coordination. A comparison of two body segments oscillating, with respect to the midline, in a mirrored symmetrical movement. The movement is produced by simultaneously contracting the same muscle groups in both limbs (Kelso, 1984; Obhi, 2004).

Index of Coordination (IdC). Quantifies the coordination of the arms while swimming through the calculation of the percent of time of each stroke where no propulsion occurs. IdC is determined by lag time between the by end of the propulsion of one arm and the start of the propulsion of the other (Chollet, Chalies and Chatard 2000).

Metabolism. The sum total of processes occurring in a living organism indicated by the rate of heat production (Brooks, 2005).

Maximal Oxygen Consumption. The maximum capability of an individual to consume oxygen (Brooks, 2005).

Modified Swim Bench. A Biokinetic Swim Bench allows for a swimming motion to be performed while in a prone position out of the water. The swim bench is similar to an incline bench where the upper body is slightly elevated above the feet. However, unlike a typical swim bench, resistance for this modified swim bench is provided by two individual weight stacks placed in front of the swim bench and attached to hand paddles. The separate weight stacks allow for different resistances to be applied to each arm.

Opposition Coordination. An arm coordination pattern in swimming where one arm begins the pull phase when the opposite arm is finishing the push phase, similar to anti-phase coordination (Chollet, Chalies and Chatard 2000).

Oxygen Consumption. The rate of consumption of a given volume of O_2 usually expressed in $L*min^{-1}$ or $mlO_2*kg*min^{-1}$ (Brooks, 2005).

Peak Oxygen Consumption. Highest value of oxygen consumption measured during a graded exercise test (McArdle, 2001).

Pull Phase. The time from when the hand begins a backward motion until the hand reaches the vertical plane of the shoulder (Chollet, Chalies and Chatard 2000).

Push Phase. The time from when the hand reaches the vertical plane of the shoulder until the hand is released from the water (Chollet, Chalies and Chatard 2000).

Recovery Phase. The time when the hand is out of the water (Chollet, Chalies and Chatard 2000).

Superposition Coordination. An arm coordination pattern in swimming where there is an overlap in the propulsive phases of the two arms (Chollet, Chalies and Chatard 2000).

CHAPTER 2

INTRODUCTION

An interesting phenomenon occurs during locomotion and limb movement; the limbs will spontaneously transition toward one of two coordination patterns, known as “attractor states” and are referred to as “in-phase” and “anti-phase”. The patterns not only stabilize the movement but are also performed at the lowest metabolic cost for the given speed of the movement (Holt, et al., 1995). The basic coordination patterns require neither additional cognitive attention to be maintained nor dedicated practice to acquire the pattern. Although transition patterns can occur, the limbs quickly move toward these coordination patterns; however, in swimming the front crawl, an intermediate coordination pattern between true in-phase and anti-phase is often maintained. Even though bilateral coordination plays an important role in locomotion, it is often overlooked because it is thought to be a natural phenomenon. Instead, emphasis is placed on the stride period and stride length, the two components of locomotion that combine to produce the overall movement. Similarly, in swimming, the emphasis is placed on the stroke rate (SR) and stroke length (SL). In general, bilateral coordination patterns that account for the locomotion components of a given movement have only been superficially investigated in locomotion research. This study will examine the bilateral arm coordination pattern while the arms are under an uneven load as well as the effect of the uneven load on the metabolic cost of the rhythmic movement.

REVIEW OF THE RELATED LITERATURE

Coordination of the limbs is essential for locomotion, not only for the metabolic benefits, but also for providing stability to the movement. Freely chosen movements innately develop a coordination pattern that stabilizes the movement. In swimming, just as in walking, a transition in the coordination pattern occurs with an increase in the speed of the movement. This study will evaluate changes in the metabolic cost associated with potentially compromised arm coordination in swimming.

The literature pertaining to interlimb coordination and propulsive swim forces will be reviewed. The review will be presented in the following manner: (1) Movement Coordination, (2) Coordination and Metabolic Cost, (3) Asymmetric Force Production, (4) Proposed Uneven Arm Load Protocol, (5) and Summary.

1. MOVEMENT COORDINATION

Movement coordination refers to the act of controlling one overall body motion with the movement of two or more body parts to produce a skilled activity (Schmidt, 1995). It also describes the linked motion of joints or limbs that move at the same time. The body segments can work together, as seen with the arms and legs while walking, or one segment can control the movement of the other, as apparent during transitions in coordination. The coordination of a movement is often not controlled by one limb but by the frequency at which both segments are moving. A change in the frequency of the movement alone can initiate a transition in the chosen coordination pattern.

Limb Frequency

When given the option of choosing a pace at which to walk, animals and humans alike will select a highly predictable frequency (Goodman, et al., 2000; Holt, et al., 1990b, 1991; Holt, et al., 1995) that is characterized by being the most economical for the movement in terms of increasing stability and occurring at the lowest metabolic cost. This frequency is thought to be a learned process that is honed when a person first begins walking. A person will make changes to the trajectory of the limbs, trunk, and head until a stable style is found. This pattern leads to minimal changes in trunk and head positions throughout the motion resulting in the fewest number of compensatory contractions needed to maintain balance (Holt, et al., 1995).

The self-selection of a frequency is also observed in other rhythmic movements (e.g. rowing (Salvendy & Pilitsis, 1971) and swimming (Alberty et al., 2008). Rhythmic movements are predictable by definition; the same motion is repeated over and over. When walking, the rhythmic motion allows the limbs to be in pendular motion where the limb is constantly exchanging between potential and kinetic energy states (Goodman, et al., 2000; Turvey, Holt, LaFiandra, & Fonseca, 1999). A key property of a limb in pendular motion is the resonance frequency, which allows the movement to become stabilized (Rosenblum & Turvey, 1988). During pendular motion, mechanical properties, such as the shank length and the predictable changes in the center of mass of the individual, lock the trajectory of the limbs. This drives the frequency of the observed rhythmic movements thus making the movement stable and highly predictable (Goodman, et al., 2000; Holt, Hamill, & Andres, 1990a; Holt, et al., 1990b, 1991; Holt, et al., 1995; Turvey, Schmidt, Rosenblum, & Kugler, 1988).

Coordination Patterns

The frequency of the body segments is only one part of a coordination pattern. To better describe coordination, a systematic method for classifying rhythmic patterns must exist. As alluded to previously, although a person can control which pattern occurs, attractor states will pull the pattern into one of two stable coordination patterns: in-phase and anti-phase. A simple example of an attractor state, or a stable coordination pattern that is innately performed, is the pattern that develops between the arms and legs while walking. Without any additional attention, a given arm will move in opposition to the contralateral arm and the ipsilateral leg.

To study this phenomenon, coordination between fingers is often studied by having subjects tap their index fingers on a table in tempo with a metronome (Amazeen, Ringenbach, & Amazeen, 2005; Kelso, Southard, & Goodman, 1979; Serrien, 2009). When the fingers tap simultaneously, the coordination is considered "in-phase." In-phase coordination would have the fingers oscillating, with respect to the midline, in a mirrored symmetrical movement (Obhi, 2004). This coordination pattern is produced by simultaneously contracting the same muscle groups in both limbs, which will cause the limbs to move without any lag time between the body parts (Kelso, 1984). When fingers alternate their tapping, the coordination is considered "anti-phase". Anti-phase coordination would have the fingers oscillating, with respect to the midline, in a parallel movement (Obhi, 2004). This coordination pattern is produced by simultaneously contracting antagonist muscle groups in both limbs, which will cause the limbs to move in an opposite direction without any lag time between the body parts (Kelso, 1984). While these attractor states are considered the most stable, a wide range of coordination patterns are used to successfully perform simple to complex tasks from patting out a rhythm on a drum to a pianist performing different rhythms with each hand.

Measuring Coordination

There are several methods that are used to measure coordination patterns. A qualitative coordination determination utilizes a simple displacement plot of the two body segments involved to depict the coordination. For a more quantitative measurement, however, relative phase calculations are able to compare the coordination patterns over the entire movement (Kelso, 1984).

An example of this is as follows: the index fingers of an individual are tapping out a rhythm on a table. Displacement plots depict where the fingers are during a distinct location of the movement, such as the highest point in the tap and when the finger is on the table. These plots are useful for descriptive purposes and can produce a general coordination pattern; however, the plots do not produce a quantitative measurement for the entire coordination pattern. A quantitative value can be determined by analyzing the displacement of the joint during the entire cycle over time, which allows the coordination patterns to be compared. Interlimb coordination can be compared using relative phase (Φ) (Kelso, 1984; Swinnen, 2002). When the body part displacement is plotted against its velocity, called a phase-plane representation, the body part can be examined at any portion of the movement and be described as a phase angle ($\boldsymbol{\theta}$). Relative phase is the difference in the position of each limb. The position is measured as the degrees away from the natural location of the limb ($\boldsymbol{\theta}_1 - \boldsymbol{\theta}_2$) (Post, Peper, & Beek, 2000). Haken et al. (1985) demonstrated that relative phase can also be used to measure the role different variables have on the transition in coordination.

Even though displacement plots do not quantify the coordination pattern, these plots can be useful for describing the coordination at an endpoint of a movement. Kelso et al. (1986) used this method to determine relative phases from the peak-to-peak displacement of fingers by comparing the peak point of one finger with the position of the other finger in its cycle. These plots are useful for characterizing coordination when the pattern has become stable and is not under the stress to transition towards a more stable coordination pattern. However, when observing more complex movement, such as swimming, describing the entire movement becomes more important than just the distinct end points. Along with the nonlinear trajectory of the arm during a front crawl pull, stable coordination patterns are not represented by the typical in-phase or anti-phase coordination patterns.

Front Crawl Coordination Patterns

Quantifying arm coordination during a front crawl movement has been more challenging than other movements due in part to the non-linear trajectory of the arms. Comparisons between the front crawl coordination patterns and those observed during walking are hindered by the differences in the limb trajectories; however, by examining the relative phases of only the arms during the front crawl movement and only the legs while walking, similarities between the two movements become apparent and can be easily compared. Chollet and his colleagues (2000) developed the "index of coordination" (IdC) as a means to compare the arm coordination of the front crawl. The IdC classifies the bilateral arm coordination into three distinct patterns, including the traditional *in-phase* and *anti-phase* coordination patterns and the *catch-up* coordination.

The limited existing research on arm coordination that is most related to swimming motions focuses mainly on the factors that might affect arm coordination, such as arm length and stroke rate (Chatard, Lavoie, & Lacour, 1990; Nikodelis, Kollias, & Hatzitaki, 2005; Pelayo, Sidney, Kherif, Chollet, & Tourny, 1996; Toussaint et al., 1988). These studies unfortunately do not directly address arm coordination. Stroke rate and stroke length are the two most commonly adjustable factors that can be manipulated while performing a front crawl movement, and researchers often manipulate these factors to study the resulting change in coordination. This is similar to manipulating stride frequency and stride length while walking.

Stroke Rate and Stroke Length during Front Crawl Swimming

A swimming motion has been selected to understand bilateral arm coordination because the arms produce the main propulsive force during this mode of locomotion. The relationship between stroke rate and stroke length affect the coordination patterns that develop during a front crawl movement. These two variables can be, at times, inversely related such that as one increases, the other must decrease. The optimum combination which produces the greatest velocity occurs with a slightly higher stroke rate (Craig & Pendergast, 1979). When controlling the pace of a given swim, a swimmer will usually manipulate his or her stroke rate, the length of the stroke, or both based on perception (Maglischo, 2003). The selection of a particular stroke rate to stroke length ratio was further investigated by examining the relationship between energy expenditure and velocity, stroke rate, and stroke length (Chollet, Pelayo, Delaplace, Tourny, & Sidney, 1997). When a specific velocity was imposed, the swimmer decreased stroke rate and increased stroke length to compensate. Interestingly, the imposed velocity was based on the self-selected pace without the subject's knowledge. The adjusted ratio indicates that the stroke rate to stroke length ratio is intuitively selected by a swimmer to be the most effective. Altering the ratio might cause the swimmer to expend more energy than is needed. Nevertheless, maximal velocity has been shown to be directly related to the maximal stroke length of the swimmer. Championship swimmers are those who are able to cover the most distance in one stroke are also able to obtain the highest maximal velocity (Craig & Pendergast, 1979).

Index of Coordination

As previously mentioned, interlimb coordination patterns easily transition towards the more stable coordination patterns of in-phase and anti-phase. When coordinating limbs through air, there is no external resistance prohibiting this transition from occurring. Locomotion through water, on the other hand, has to compensate for the external resistance of the water at different phases of the stroke. Wannier et al. (2001) observed that while swimming, the leg frequency outpaced the frequency of the arms by a factor of five. This imbalance between the arms and legs was eliminated when the swimmers performed a swimming motion on their backs or were suspended in the air. This allowed the coordination pattern of the swimming movement to become similar to that of walking: the ipsilateral arm and leg in anti-phase (Wannier, et al., 2001).

The movement of the arms during a pull cycle, unlike a walk cycle, is not linear, which makes determining the coordination pattern difficult (Chollet, et al., 2000). During a front crawl stroke, the arms rotate; the arms work underwater against water resistance for a portion of the cycle with the remainder of the stroke moving through the air. The arm and forearm will change positions throughout the stroke as the swimmer tries to push and pull his or her body through the water. To determine coordination, the rotation of the swim cycle is broken down into four separate components: the glide and catch, the pull, the push, and the recovery (Chollet, et al., 2000). The glide and catch of the stroke starts when the swimmer's hand enters the water and continues until the swimmer initiates a backward motion. The pull begins once a backwards motion occurs and ends when the swimmer's hand aligns with the shoulder in a vertical plane. The push then begins and consists of the rest of the time the swimmer's hand is underwater. The recovery phase starts when the swimmer's hand exits the water and continues while the hand is traveling above the water; it ends once the hand enters the water. The pull and the push components create the propulsive phase of the stroke while the glide and catch and the recovery compose the non-propulsive phase. During the propulsive phase, the swimmer possibly applies force against the water to create a forward movement. To quantify the coordination of a stroke, Chollet et al. (2000) calculated the percent of the total stroke spent in each of the phases. The IdC is calculated as the percent of the stroke where no propulsive force is being applied, the lag time (LT). If there is no LT, the coordination of the stroke is opposition; if there is a positive LT (i.e. time with no propulsive force), the coordination was catch-up, and if there is a negative LT (i.e. recovery phase of one arm occurs before the pull phase of the other arm), the coordination is superposition (Chollet, et al., 2000).

Selection of Coordination Patterns

The selection of an arm coordination pattern while swimming was examined by Seifert et al. (2004). They showed that the coordination of the arms was determined by the chosen pace of the swimmer in the water, which has similarly been observed for walking in treadmill tests (Goodman, et al., 2000; Holt, et al., 1990b, 1991; Holt, et al., 1995). The coordination of the arms went from a catch up (negative LT) during longer distances at slower velocities to an opposition (little or no LT) or even to a superposition (positive LT) coordination pattern during shorter distances at higher velocities (Seifert, Chollet, & Bardy, 2004). The push towards superposition coordination occurs as the speed of the swim increases, which places additional resistance on the swimmer by the water (Nikodelis, et al., 2005).

Coordination patterns during swimming can be studied by controlling parameters similar to those controlled during walking or finger tapping. The impact of bilateral arm coordination was examined by Alberty et al. (2008) through measuring changes in the IdC of swimmers while a specific stroke rate and pace were imposed. To comply with these restrictions, the swimmers were forced to commit to a single coordination pattern. The stroke rate and pace constraints had a positive impact on the technique of the swimmers by creating a consistent propulsive phase of the arm stroke; however, as the distance of the event shortened or the swimmer experienced fatigue, the coordination of the swimmers went from a catch-up pattern to nearly an anti-phase pattern without a change in stroke rate. It was hypothesized that a transition in coordination occurs to maximize the amount of time spent in the propulsive phase and to limit the amount of time spent between the propulsive and recovery phases where no force is placed upon the water (Alberty, et al., 2008; Alberty et al., 2006; Schnitzler, Seifert, Ernwein, & Chollet, 2008; Seifert, Chollet, & Rouard, 2007). By maintaining propulsive forces, the swimmer will be sustaining the swimming speed instead of producing greater acceleration peaks and decelerations valleys that occur with uneven propulsive forces during a given stroke. The selection of a specific coordination pattern at a given speed has also been observed in walking and is believed to be explained by the metabolic demand of different coordination patterns (Holt, et al., 1991).

Although the selection of a coordination pattern has been reported to be dependent on the length of the swim, coordination may also be affected by the speed of the swim, differences in skill levels, and the sex of the swimmer. The IdC of elite men, mid-level men, and elite women swimmers were compared by Seifert et al. (2007), and a regression analysis showed that both gender (8.3%) and skill level (9%) had an effect on coordination. This supports a previous study by Seifert et al. (2004) that showed that elite men were able to increase IdC to a positive value (anti-phase) while elite women swimmers maintained a negative value throughout the distance (catch-up). Interestingly, the IdC remained the same for both the men and women swimmers during the longer events (from the 200 m distance to the 400 m distance). These results suggest that in order to compare arm coordination, subjects must be at the same skill level and either of the same sex or at a pace representing an event longer than 200 m.

In summary, bilateral limb coordination is affected by many variables. A preferred frequency is developed based on the pendular motion mechanical properties associated with the limbs that are in motion and are used to stabilize the given movement. These parameters are related to the coordination patterns that develop and drive coordination towards the attractor states. Although anti-phase and in-phase are considered stable for most bilateral movements, coordination patterns while performing a swimming motion can be placed into three stable categories: opposition, superposition, and catch-up. The transition in coordination that occurs with a change in frequency during walking similarly occurs in swimming. Frequency and stride length in walking and the stroke rate and stroke length in swimming have an impact on the overall coordination pattern that develops. Coordination patterns while walking are compared by examining the relative phase of the limbs; similarly, the IdC allows for the patterns observed during a swimming motion to be quantified. Relative phase and the IdC are used to compare coordination patterns at different speeds and between subjects. Due to sex differences and the effect of skill level on coordination patterns, these variables must be considered when comparing IdC between subjects. Although given coordination patterns naturally develop for a given movement, examining the benefit of coordinating limbs on the metabolic cost of the movement is important to understand this phenomenon.

2. COORDINATION AND METABOLIC COST

Metabolic Benefits of Coordination

Coordination has been suggested to optimize a movement through the selection of a frequency and stabilization. These two factors, frequency and stabilization, are related and have been used to explain why a coordinated movement requires the minimal metabolic cost for maintaining a motion. The resonance frequency of human movement occurs at a frequency that allows body segments to provide assistance to maintain the movement. This includes the swinging of the arms or utilizing the exchange between potential and kinetic energy states while walking (Goodman, 2000; Turvey, 1999). The resonance frequency minimizes the metabolic cost by utilizing gravity to limit the force that must be applied by the muscles to maintain locomotion (Holt, et al., 1991; Holt, et al., 1995). Along with the resonance frequency, the positioning of the limbs during the movement can affect the metabolic cost of a movement; slight changes in the center of mass throughout the movement can increase the metabolic demand. Holt et al. (1995) examined the metabolic cost of subjects walking at their preferred frequency, a predicted frequency, three frequencies above the predicted frequency, and three frequencies below the predicted frequency. The findings were not surprising in that the lowest metabolic cost occurred with the preferred and predicted frequencies; however, the stability of the trajectory of the head was also greatest just below the predicted frequency. The selection of a frequency and the stabilization of the head movement while walking are thought to be learned through trial and error when an individual first begins to walk; the frequency requiring the least amount of energy is preserved. The stabilized head position limits additional changes to the center of mass outside the normal rise and fall that occurs during walking (Holt, et al., 1995). Practicing novel tasks has provided similar conclusions about frequency and stabilization as specific parameters, such as stride length and cycle duration in rowing exercises, are modified (Sparrow, Hughes, Russell, & Le Rossignol, 1999). Imposing frequencies above or below the preferred frequency increases the metabolic demand of the movement. It was suggested by Sparrow et al. (1999) that the preferred rate develops based upon anthropometric characteristics and thus is specific to each individual.

Although several studies have examined the metabolic benefits of coordination, there have not been studies that have examined the effects of arm coordination on the metabolic cost while swimming, either in the water or on a swim bench. The additional resistance that occurs while swimming in water has limited research involving swimming as a mode of locomotion; however, utilizing a swim bench would remove some of the uncontrolled environmental variables that exist in a pool.

3. Asymmetric Force Production

Coordination between limbs is traditionally studied using finger taps on different hands. However, this does not provide useful information on coordinated locomotor movement in humans. As previously discussed, coordination between limbs is used to stabilize a movement. The stabilizing effect remains in asymmetrically perturbed limbs, which is created through altering the mass of one or both limbs while performing the same movement. Loading a single arm alters the movement of both arms while walking (Donker, Mulder, Nienhuis, & Duysens, 2002). Under this asymmetric loading condition, Donker et al. measured a decrease in the range of movement of the perturbed arm while the range of movement of the non-perturbed arm was increased; however, even with the perturbed arm moving a shorter distance, both arms showed an increase in muscle activation. This is suggested to be an attempt by the neuromuscular system to maintain a constant output (Donker, et al., 2002). The constant output would benefit the individual by preserving stability and reducing the amount of attention needed to maintain balance.

To examine the coordination of limbs that have a more direct effect on locomotion, the human gait has been examined. Russell et al. (2010) measured the coordination dynamics of walking through the creation of an asymmetric movement. There were five conditions that were created by adding 3 kg weights, 6 kg weights, or no load to either ankle. This method of attaching weight to one or both limbs to interrupt the normal coordination pattern between limbs has been used in previous studies (Donker, Daffertshofer, & Beek, 2005; Donker, et al., 2002;

Jeka & Kelso, 1995; Noble & Prentice, 2006); however, Russell et al. (2010) noted that the addition of weight smaller than what was used in their study was not able to create a significant asymmetric movement. Instead, their study required the subjects to walk at a constant speed on a treadmill while under one of five conditions created by adding weight to one leg at a time. To allow for the optimum stride period to develop during one condition, the subject was not given feedback, which would have forced a predicted stride period based on the lower limb characteristics of the subject. However, a second condition controlled stride period through the use of a metronome set at a pace predicted using the Haken-Kelso-Bunz model (HKB) (Haken, Kelso, & Bunz, 1985). In this condition, subjects were instructed to match the heel strike of their right foot with each consecutive beat. Each subject completed 30 trials lasting 40 seconds each with analysis performed during the last 30 seconds of the trial. The short trial duration limited the subject's ability to explore different movement parameters that could influence the metabolic cost of the movement (Russell, Kalbach, Massimini, & Martinez-Garza, 2010).

The results of the asymmetric conditions were similar for both the non-metronome and the metronome condition; however, changes in the stride period of the right foot were significantly smaller during the non-metronome condition. The relative phase between the right and left heel strike was dependent on the metronome; with the relative phase of the non-metronome condition, the heel strikes of each foot fell further apart. Both conditions did show that the leg with the slower resonance frequency (i.e. the leg with the increased weight) fell behind the other leg.

The experiment by Russell et al. (2010) investigated interlimb coordination through loading one limb at a time. Previous studies (Donker, et al., 2005; Donker, et al., 2002) were unsuccessful in producing a significant difference in the coordinating limbs. This is possibly due to the methods used for increasing the load on a given limb, the amount of weight added, or altering the subject's stride frequency. Russell et al. (2010) were able to overcome these by adding weight not only to the right side but also to the left side. Also, the amount of weight added was greater than in previous studies. Furthermore, by allowing the subjects to walk at their preferred frequency, these researchers allowed for the pace to occur at the natural resonance frequency of the limbs. The results led the researchers to conclude that the preferred stride period during walking is due in part to the stability provided during a pendular motion. Other factors, such as oxygen consumption (Zarrugh, Todd, & Ralston, 1974) or the influence of stability and optimizing the metabolic cost (Holt, et al., 1995) could also factor into the development of the stride period of a movement. These were not considered to play a major role in the study given that the short duration of each trial, 40 seconds, would not be long enough for subjects to make adjustments to account for those factors. A further exploration of interlimb coordination through the use of uneven limb loading is needed to determine the effects of coordination on oxygen consumption and movement stabilization.

4. Uneven Arm Loads

Russell et al. (2010) was able to apply coordination tests to locomotor movement. This was an important step in understanding the properties of locomotor coordination; however, the results are not directly applicable to typical movement patterns. The variables measured, such as stride period and interlimb coordination, were determined after only a short period of time, but more importantly, other variables were not considered. Coordination factors, such as balance and the metabolic demand, that do not play a significant role in the finger and wrist coordination tests play a much larger role in locomotion.

The current study will look to examine the coordination factors that directly affect locomotion, such as oxygen consumption and interlimb coordination during a locomotor movement. The current study will measure coordination by utilizing a modified pulley-weight stack (MPWS), similar to the Biokinetic Swim Bench (Isokinetic inc.) that has been used in previous research (e.g. preferred stroke rate (I. Swaine & Reilly, 1983), cardiopulmonary response (I. L. Swaine & Winter, 1999), power imbalance (Potts, Charlton, & Smith, 2002)). The MPWS is used to mimic the swimming motions that occur in the water while being able to control the weights each arm will pull throughout the front crawl motion. This position on the bench will reduce the need for attention to maintaining balance since the body of the subject will be supported. Although the movement patterns on the MWPS and swim bench do not perfectly replicate the swimming patterns, the joint angles and contracting muscle groups are similar (Sharp, Troup, & Costill, 1982). Subjects will perform three trials with three conditions for a total of nine bouts. Workload for the trials will be determined by a percentage of the subject's VO_{2Peak}, which will be determined one week prior to the coordination trials. Each trial will have an even arm load distribution (EL) and two uneven arm load distributions, right arm loading (RL) and left arm loading (LL). During the RL condition, additional weight will be attached to the weight stack the right arm is pulling. This weight will be removed from the left arm's weight stack, which will keep the total workload equal to the workload during the EL condition. The LL condition will place additional weight to the left arm's weight stack and remove the same amount of weight from the right arm's weight stack, once again keeping the total workload equal to the workload during the EL condition. To ensure that the same amount of work will be done during each condition, a constant stroke rate (SR) and stroke length (SL) will be imposed. The preferred SR and SL will be determined prior to the VO_{2max} test and will be used throughout the trials.

Arm coordination throughout the trials will be determined using the IdC as described by Chollet et al. (2000), with the exception that the swimmer will be on the MWPS and not in the water. The propulsive phase will be determined as the time from the initiation of the pull until the initiation of the recovery, and the recovery phase will consist of the time from the initiation of the recovery until the initiation of the pull for each stroke. While the SR and SL will be held constant throughout the trials, the subjects will be able to change their coordination as needed through changes in the ratio of the time spent in the propulsive and recovery phases.

5. Summary

This study will look to examine interlimb locomotor coordination dynamics through uneven arm loading. This method is the standard method used for measuring coordination dynamics. The results from finger tapping experiments were suggested to be applicable to locomotion, and Russell et al. (2010) successfully applied these concepts to quantify locomotor coordination dynamics. This finding makes it possible to measure the effect of perturbing the limbs that are creating the propulsive forces during the rhythmic movement through changes in the metabolic cost of the movement and changes in bilateral coordination. A greater understanding of these factors will contribute to the knowledge of the coordination dynamics during locomotion.

Based on the pertinent literature, the current study should produce similar results as Russell et al. (2010). The self-selected stroke rates of the subjects, maintained throughout the trials, will allow the subjects to produce the movement at their resonance frequency during the EL. During the uneven loads, RL and LL, it is expected that the movement will be perturbed to the point that it affects the coordination of the limbs. This will be measured using the IdC. Given the length of each bout, it is expected that the IdC during the EL will be negative, representing a catch-up coordination pattern. During the RL and LL conditions, the IdC should be less negative, representing a transition from the catch-up coordination pattern to an opposition coordination pattern. Along with this transition in coordination patterns, the metabolic demand of the movement is also expected to increase, indicated by an increase in the oxygen consumption.

CHAPTER 3

METHODOLOGY

The purpose of the study was to investigate the metabolic cost of arm coordination associated with a change in load distribution between two arms. The conduct of the study will include the following organizational steps: (a) Arrangements for Conducting the Study; (b) Selection of Subjects; (c) Selection of the Instrumentation; (d) Procedures for Testing; and (e) Treatment of Data.

Arrangements for Conducting the Study

The study was conducted in the Human Performance Laboratory at Indiana University, Bloomington, Indiana upon approval by Indiana University's Institutional Review Board (study # 1005001342). The researcher met with potential subjects to go over information about the study, such as the purpose of the study and procedures involved. A signed informed consent form was obtained from every subject prior to his participation in the study.

Selection of Subjects

All of the subjects (n=15) were volunteers recruited through the Indiana University Swim Club, Indiana University Masters Swim Club, and Bloomington area swim clubs. Subjects were non-elite competitive male swimmers. "Non-elite" was defined by not qualifying for the 2009 US Short Course Nationals in the 50 yd or 100 yd freestyle event (qualifying time: 20.99 seconds (s) and 45.99 s, respectively) nor qualifying for the 2010 US Nationals in the 50 m or 100 m freestyle events (qualifying cuts: 23.59 s and 51.79 s, respectively). Previous studies have defined elite athletes by swim times as a percent of the world record (Schnitzler, et al., 2008; Tourny-Chollet, Seifert, & Chollet, 2009) or by being a member of a national team (Barbosa, Fernandes, Keskinen, & Vilas-Boas, 2008; Nikodelis, et al., 2005). A difference in the index of coordination (IdC) exists throughout a range of distances among elite male swimmers, non-elite male swimmers, and elite female swimmers but not between non-elite male and elite female swimmers (Schnitzler, et al., 2008). However, since no comparisons between non-elite male and non-elite female swimmers have been made, only male swimmers were utilized for the current experiment. In addition to differences in the IdC, it has been previously reported that the metabolic cost for a given velocity is sex-dependent (Pendergast, Diprampero, Craig, Wilson, & Rennie, 1977). The main criteria for participation included: (a) all subjects were men and between the age of 16 and 29 years; (b) all subjects were determined to be non-elite based on a swimming history questionnaire; (c) all subjects were determined to be able to exercise at a low risk using a modified physical activity readiness questionnaire (PAR-Q); (d) and all subjects did not currently have any diagnosed shoulder injuries or previous injuries that would have prevented them from performing a freestyle motion.

Selection of the Instrumentation

The following equipment was utilized in the coordination trials. A digital scale was used to measure the subject's mass, which was used for the maximal aerobic capacity exercise test and for descriptive purposes. A stadiometer was used to measure the heights of the subjects for descriptive purposes. The coordination trials occurred on a modified pulley-weight stack (MPWS). The MPWS allowed the subjects to perform a pulling movement that was similar to the front crawl swimming motion (Sharp, et al., 1982). The subjects performed the pulling motion while lying in a prone position on a bench that was attached to the MPWS. The loads were provided by two separate weight stacks that were attached to hand paddles that the subject could pull. Having two independent weight stacks allowed different loads to be placed on each arm at the same time. Two tachometers attached to the pulleys of the MPWS were connected to an analog to digital converter board which inputs data to a Dell computer running a data acquisition control system (DasyLab 10, measX GmbH & Co. KG Moenchengladbach, Germany). The tachometers measured the velocity of the stroke throughout the pull and the length of each pull. The initiation and termination of each arm pull was determined by a velocity of 0 $m*sec^{-1}$, which indicated a change in direction of the arm. Stroke length (m), stroke rate ($S*min^{-1}$), and average stroke speed ($m*sec^{-1}$) were all calculated from the tachometer output. The subjects wore nose clips and were connected to a rubber mouthpiece attached to a two-way non-rebreathing valve (Hans Rudolph, model# 2700, Hans Rudolph, Inc., Shawnee, KS) with the expired side of the valve connected to a 5 L mixing chamber. Gases were sampled at a rate of 150 $ml*min^{-1}$ by an Applied Electrochemistry S-3A oxygen analyzer and CD-3A carbon dioxide analyzer (Ametek, Thermox Instruments, Pittsburgh, PA). The analyzers were connected to the same data acquisition control system (DasyLab 10, measX GmbH & Co.KG Moenchengladbach, Germany) as the tachometers. The flow rate was measured from the inspired end of the two-way valve using a turbine-based electronic flow meter (Model VMM-2: Sensormedics Anaheim, CA). During the coordination trials, each subject wore a heart rate monitor (Polar T61) around his chest to measure heart rate every 30 seconds.

Procedures for Testing

Anthropometry

Body mass was measured using a digital scale. Each subject was instructed to sit on a stool in the center of the scale while being measured. Mass was recorded to the nearest 0.01 kg. Height was obtained using a stadiometer while the subject stood with his heels, buttocks, and back against a wall. A wooden board was placed on the top of the subject’s head to accurately measure height. Height was recorded to the nearest 0.1 cm. Ambient conditions of the testing environment were assessed by recording barometric pressure (mmHg) and room air temperature (°C).

Familiarization

Prior to the start of the peak aerobic capacity test and the arm coordination test, subjects were allowed a five minute period to become familiar with the equipment. The subject was instructed to lie on his stomach on the bench of the MPWS with his head extending just beyond the bench. The bench was similar to an incline bench where the upper body of the subject was slightly elevated above his feet. A stool was provided to support the legs of the subject. The subject was in this position throughout both testing sessions. The subject was handed a hand paddle for each hand and asked to mimic a typical front crawl swimming motion while pulling the weight stacks attached to each hand paddle. The subject had a chance to try an even weight loading profile that would be tested during the peak aerobic exercise. The weight load was set at 3.4 kg per arm, and the subject was instructed to pull at a pace of 65 beats per minute. The subject was instructed to initiate a pull at the sound of the metronome, alternating pulling the paddles with the right and left arm. At the end of the familiarization period, the stroke rate was either increased or decreased to allow the subject to pull at a preferred stroke rate. During the peak aerobic exercise and the coordination trials, the subject's preferred stroke rate was imposed using a metronome placed below the subject.

Peak Aerobic Capacity Exercise Test

The subject was instructed on where to attach the heart rate monitor around his chest and then instructed to lie on the bench in the same position as the familiarization trail. Once in the proper position, the subject was fitted with a rubber mouthpiece attached to a Hans Rudolph two-way valve and nose clip, which was worn throughout the duration of the test. Rubber mouthpieces were cleansed in a detergent solution and submerged in an antibacterial solution following each use. The subject wore a heart rate monitor in order for heart rate to be recorded. The peak aerobic capacity test began with 5 minutes of rest while the subject lied quietly on the bench breathing through the mouthpiece and wearing the nose clip. During this rest period, baseline oxygen consumption (VO_2) and resting heart rate were measured. Gases were continuously analyzed and reported as average minute values using the O_2 and CO_2 analyzers previously described. The final average minute VO_2 and final recorded HR were considered the resting values. At the completion of the resting period, the discontinuous peak aerobic capacity test commenced. The subject was instructed to pull the arm paddles, mimicking a normal freestyle pull, for 4 minutes at his preferred stroke rate. Feedback on the stroke rate was provided by a metronome placed beneath the subject. At the completion of each minute, if the total number of strokes was either above or below the stroke rate, the subject was instructed to decrease or increase his stroke rate, respectively. The initial arm load was set at 2 kg per arm. The arm load was increased by 0.7 kg increments following each 4-minute exercise bout. The test was terminated if the subject no longer wished to continue or one of the following conditions occurred: (1) volitional fatigue, (2) inability to maintain the required stroke rate, (3) no further increase in oxygen consumption with an increase in workload was noted, (4) the subject exceeded his age-predicted heart rate by more than 10 beats per minute, or (5) the respiratory exchange ratio (RER) exceeded 1.10. If only conditions 1 and/or 2 were met, the subject was asked if he could complete the next stage after a 10-minute rest period. If he agreed, a 10-minute rest period began, and the subject continued the test at the end of the rest period. If the subject felt he could no longer continue even with the additional rest, the test was terminated.

Measurements for VO_2 and RER were collected in 60 second intervals. HR was recorded in 30 second intervals. Stroke characteristics were measured continuously during the trial using the data acquisition software previously mentioned. The testing session lasted approximately 120 minutes.

The amount of work performed during the last minute of each stage was determined for each subject following the testing session. The amount of work was calculated as the product of the length of each stroke and the amount of weight pulled by the arm. Measurements for both the right and left arms were determined separately and then combined to find the total workload of the stage. A linear regression between the stage and total work was used to predict stages that corresponded with 50%, 65%, and 80% of the workload at a subject's VO_{2Peak}. Subjects were excluded from the study if a workload corresponding to 50% of the subject's VO_{2Peak} was below the second stage of the peak aerobic capacity test. All other subjects were scheduled for the arm coordination test a week following the peak aerobic capacity test.

Arm Coordination Tests

For the arm coordination test, the subjects were connected to the mouthpiece and Hans Rudolph valve in order to analyze gases throughout the test. Each subject performed three trials (even arm load (EL), right arm loaded (RL), and left arm loaded (LL)) in a random order. Each trial consisted of a 5-minute submaximal exercise bout to determine arm coordination. Throughout each trial, the subjects were in a prone position on the bench, the same position as the familiarization trial and the peak aerobic capacity test. The subjects were handed two hand paddles for them to grasp in each hand. Each paddle was attached to a separate weight stack, which allowed different loads to be attached to each paddle. The bench that the subject lied on allowed the subject to pull the paddles, while in a prone position, in a motion similar to that of swimming the front crawl. Each subject pulled the hand paddles in a swim stroke motion at his preferred stroke rate. The stroke rate was administered using a metronome placed underneath the subject (Swaine, 1999). The subject used the metronome to pace himself throughout the entire 5 minutes of the coordination test. No additional feedback was given based on stroke rate. The amount of weight that was attached to each paddle depended on the trial. There were three trials corresponding to 50%, 65%, and 80% of the maximal workload performed during the peak aerobic capacity test. Each trial was composed of three conditions. For two of the three conditions, 0.7 kg was added or removed from either the right or the left arm to create uneven loads (Table 3-1).

	Trial A		Trial B		Trial C	
	Arm Load 50% $VO_{2\ Peak}$		Arm Load 65% $VO_{2\ Peak}$		Arm Load 80% $VO_{2\ Peak}$	
	Right Arm	Left Arm	Right Arm	Left Arm	Right Arm	Left Arm
EL	50% $VO_{2\ Peak}$	50% $VO_{2\ Peak}$	65% $VO_{2\ Peak}$	65% $VO_{2\ Peak}$	80% $VO_{2\ Peak}$	80% $VO_{2\ Peak}$
RL	+0.7 kg	-0.7kg	+0.7 kg	-0.7kg	+0.7 kg	-0.7kg
LL	-0.7kg	+0.7 kg	-0.7kg	+0.7 kg	-0.7kg	+0.7 kg

Table 3-1. Workloads for each trial and condition.

The trials and the conditions within each trial were administered in a random order. HR was recorded in 30 second intervals throughout each trial. There was a 5-minute recovery period between each condition in a trial and a 10-minute recovery period between each trial. During the rest periods, the subject's blood pressure (BP) was taken using a standard sphygmomanometer from the right arm of the subject. Testing was terminated with a BP reading at or above 260/111 mmHg. The subject was then allowed to come off the swim bench and rest in a chair for the remainder of the rest period. At the completion of the rest period, the subject repositioned himself on the swim bench to begin the next trial.

Index of Coordination

To calculate the IdC of each arm, strokes were separated into a propulsive phase (PP) and a non-propulsive phase (NPP). The PP was defined by the initiation of a backwards motion of the paddle until the arm initiated a forward motion, which corresponded to the beginning of the NPP. The NPP concluded at the start of the PP. The initiation of both the PP and the NPP were identified using tachometers attached to each pulley. These tachometers recorded the time when each phase began as well as the length of each phase. The lag time (LT) between the start of the PP of the right arm and the start of the NPP of the left arm (LT_1) and the LT between the start of the PP of the left arm and the start of the NPP of the right arm (LT_2). The two LTs were then averaged to represent the total LT, which could then be expressed as a percent of the total stroke duration and calculate the IdC for the stroke of that arm. The following equation was used to calculate the IdC of the right arm during a stroke, $IdC = [((LT_1 + LT_2) * 2^{-1}) * (PP + NPP)^{-1}] *100$; where $LT_1 = (PP_{Right} – NPP_{Left})$ and $LT_2 = (PP_{Left} – NPP_{Right})$. The IdC classifies arm coordination into three categories: catch up (IdC < 0%), opposition (IdC = 0%), and superposition (IdC > 0%) (Table 3-2). The same calculation was made using the left arm (Chollet, et al., 2000).

	Catch Up Coordination (IdC< 0%)		
Left arm	PP	NPP	PP
Right arm	NPP	PP	NPP
Lag Time			

	Opposition Coordination (IdC = 0%)		
Left arm	PP	NPP	PP
Right arm	NPP	PP	NPP

	Superposition Coordination (IdC> 0%)		
Left arm	PP	NPP	PP
Right arm	NPP	PP	NPP
Lag Time			

Table 3-2. IdC determination for each stroke.

<u>Treatment of Data</u>

SPSS version 18.0 statistical software (SPSS Inc., Chicago, IL) was used to analyze the data.

Descriptive statistics were used to define the characteristics of the group, including age (years), height (m), weight (kg), and peak aerobic capacity (VO_{2Peak}). Data were reported as mean ± standard deviation.

To test if the added weight between workload trials increased the metabolic demand of the movement, a one-way repeated measures ANOVA was used to compare the VO_2 of the EL at the three workload trials (WL1, WL2, and WL3) with statistical significance set at $p = 0.05$. If Mauchley's test detected a violation of sphericity, a Greenhouse-Geisser adjustment was used. Where a significant difference was identified, a Bonferroni post hoc test was used to isolate the differences between trials.

To test the hypothesis that an uneven distribution of the workload will affect the metabolic cost of the movement, the VO_2 was collected throughout the arm coordination test. The final minute VO_2 values were compared between the three arm loading profiles (EL, RL, and LL) and the three workload trials (WL1, WL2, and WL3). The null hypothesis was tested with a two-way repeated measures ANOVA with significance set at $p = 0.05$. If Mauchley's test detected a violation of sphericity, a Greenhouse-Geisser adjustment was used. Where a significant difference was identified, a Bonferroni post hoc test was used to isolate the differences between trials.

To test the hypothesis that the evenly distributed workload between the arms would result in an opposition coordination pattern, the IdC values for each arm were analyzed. The last 50 strokes of each even distribution workload test were analyzed to determine an average IdC value. IdC values were calculated for both left and right arms. The evenly distributed workload condition IdC values were compared for each trial using a repeated measures design. The null hypothesis was tested with a one-way repeated measures ANOVA with significance set at $p = 0.05$. If Mauchley's test detected a violation of sphericity, a Greenhouse-Geisser adjustment was used. Where a significant difference was identified, a Bonferroni post hoc test was used to isolate the differences between trials.

To test the hypothesis that an unevenly distributed workload between the arms will cause a change in arm coordination, the IdC values for each arm were once again analyzed. The last 50 strokes of each condition were analyzed to determine an average IdC value for that condition. IdC values were determined for both the left and right arms. The IdC values were compared between the three arm loading profiles and the three workload trials using a repeated measures design for each arm. The null hypothesis was tested with a two-way repeated measures ANOVA for each arm. Significance was set at $p = 0.05$. If Mauchley's test detected a violation of sphericity, a Greenhouse-Geisser adjustment was used. Where a significant difference was identified, a Bonferroni post hoc test was used to isolate the differences between trials. To test the difference between right and left arm IdC at each condition, paired t-tests were used with significance set at $p = 0.05$.

CHAPTER 4

RESULTS

Peak Aerobic Capacity Exercise Test

Fifteen subjects completed the peak aerobic capacity test (PT) on the modified pulley-weight stack. The subjects were 21.1 (SD = 3.9) years old, 181.7 (SD = 7.3) cm in height, and weighed 79.41 (SD = 14.10) kg. Values obtained during the PT are shown in Table 4-1.

Peak Aerobic Capacity Test					
Age	Height	Weight	VO_{2Peak}	HR_{Peak}	RER_{Peak}
21.1 ± 3.9	181.7 ± 7.3	79.41 ± 14.10	29.23 ± 5.60	160 ± 16	1.06 ± 0.06

Table 4-1. Subject characteristics (n = 15) reported as mean ± standard deviation. Age: years; Height: cm; Weight: kg; VO_{2Peak}: $mL*kg^{-1}*min^{-1}$; HR_{Peak}: $beats*min^{-1}$.

Analysis of the measurements recorded during the PT determined the workloads for each subject's arm coordination test. If the calculated workload corresponding to 50% of the workload at VO_{2Peak} occurred below the second stage, subjects were eliminated from the arm coordination test. This resulted in the elimination of four subjects.

Eleven subjects qualified for further participation in the study and completed the arm coordination test. Values obtained during the PT for this group are shown in Table 4-2.

Peak Aerobic Capacity Test					
Age	Height	Weight	VO_{2Peak}	HR_{Peak}	RER_{Peak}
21.4 ± 4.4	184.0 ± 6.5	82.42 ± 15.17	30.11 ± 5.99	160 ± 19	1.04 ± 0.05

Table 4-2. Subject characteristics (n = 11) reported as mean ± standard deviation. Age: years; Height: cm; Weight: kg; VO_{2Peak}: $mL*kg^{-1}*min^{-1}$; HR_{Peak}: $beats*min^{-1}$.

Arm Coordination Tests

A one-way repeated measures ANOVA was used to compare the VO_2 of the subjects during the even loading profile (EL) among the three workload trials (50% of workload at

VO_{2Peak} (WL1), 65% of workload at VO_{2Peak} (WL2), and 80% of workload at VO_{2Peak} (WL3)). There was a significant main effect for VO_2 between the workload trials ($p = 0.005$). A Bonferroni post hoc test showed significant differences between the EL at WL1 and EL at WL2 ($p = 0.004$) and between EL at WL1 and EL at WL3 ($p = 0.019$). There was no significant difference between EL at WL2 and EL at WL3 ($p = 0.290$) (Figure 4-1).

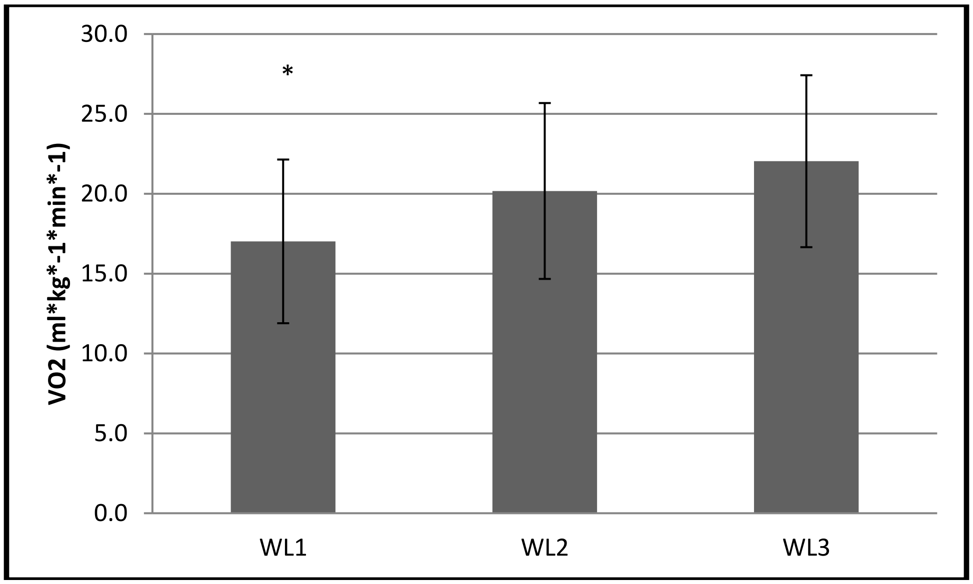

Figure 4-1. Oxygen consumption (VO_2) during the even loading profile of the arm coordination trials. Each trial consisted of a workload corresponding to 50% of the workload at VO_{2Peak} (WL1), a workload corresponding to 65% of the workload at VO_{2Peak} (WL2), or a workload corresponding to 80% of the workload at VO_{2Peak} (WL3).
* Significantly different from WL2 and WL3 ($p <0.05$)

A two-way repeated measures ANOVA was used to compare the VO_2 of the subjects between the three workload trials (WL1, WL2 and WL3) and the three arm loading profiles (EL, right loading profile (RL) and left loading profile (LL)). There was not a significant interaction between the workload trials and the three arm loading profiles ($p = 0.719$). There was a significant main effect for VO_2 between the workload trials ($p = 0.001$). A Bonferroni post hoc test showed significant differences between WL1 and WL2 ($p = 0.006$) and WL1and WL3 (p =

0.013). No significant differences were found between WL2 and WL3 ($p = 0.209$) (Figure 4-2). There was not a significant main effect for the loading profile ($p = 0.767$).

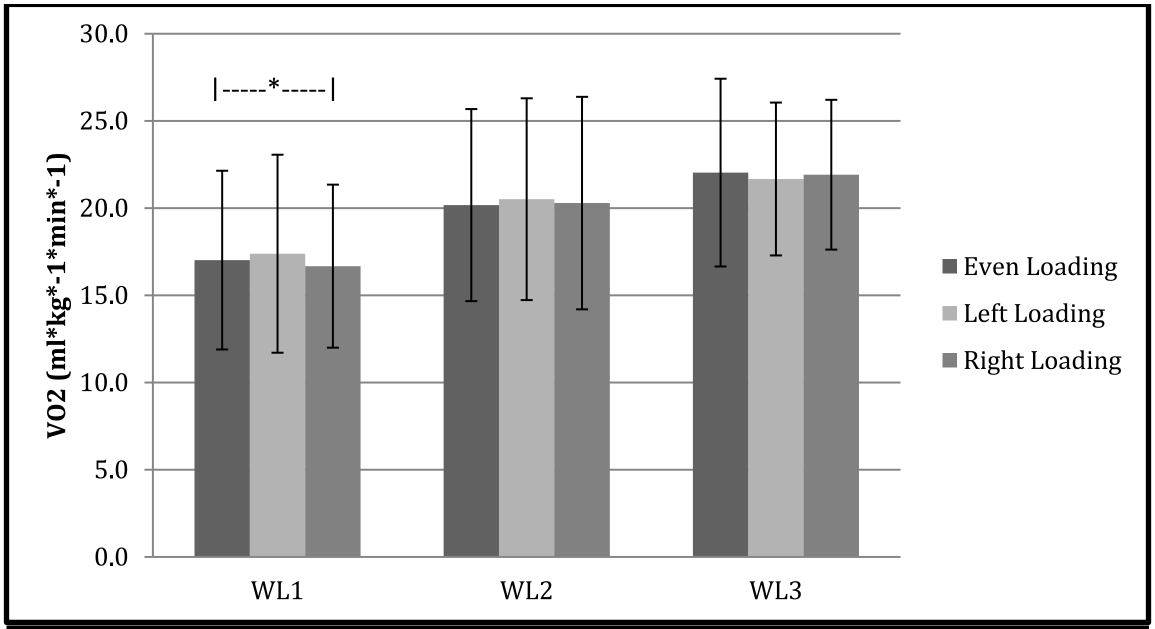

Figure 4-2. Oxygen consumption (VO_2) during arm coordination trials. Each arm loading profile consisted of a workload corresponding to 50% of the workload at VO_{2Peak} (WL1), a workload corresponding to 65% of the workload at VO_{2Peak} (WL2), and a workload corresponding to 80% of the workload at VO_{2Peak} (WL3).
* Significantly different from WL2 and WL3 ($p < 0.05$)

Index of Coordination

The mean index of coordination (IdC) for all subjects indicated a superposition coordination pattern throughout the trials (Table 4-3). A one-way repeated measures ANOVA was used to compare the EL IdC between the three workload trials for both the right arm and the left arm. No significant difference was found for either the right arm ($p = 0.322$) or for the left arm ($p = 0.361$) (Figure 4-3).

	WL1			WL2			WL3		
	EL	LL	RL	EL	LL	RL	EL	LL	RL
Right Arm	3.1 ± 2.4	3.1 ± 2.4	2.6 ± 2.5	2.6 ± 2.7	3.0 ± 2.5	2.5 ± 2.6	2.8 ± 2.6	2.6 ± 2.4	3.2 ± 2.7
Left Arm	3.2 ± 2.4	3.1 ± 2.4	2.7 ± 2.5	2.7 ± 2.7	3.0 ± 2.5	2.5 ± 2.5	2.8 ± 2.6	2.6 ± 2.4	3.2 ± 2.7

Table 4-3. Index of coordination (%) during the arm coordination trials (n=11) reported as mean ± standard deviation.

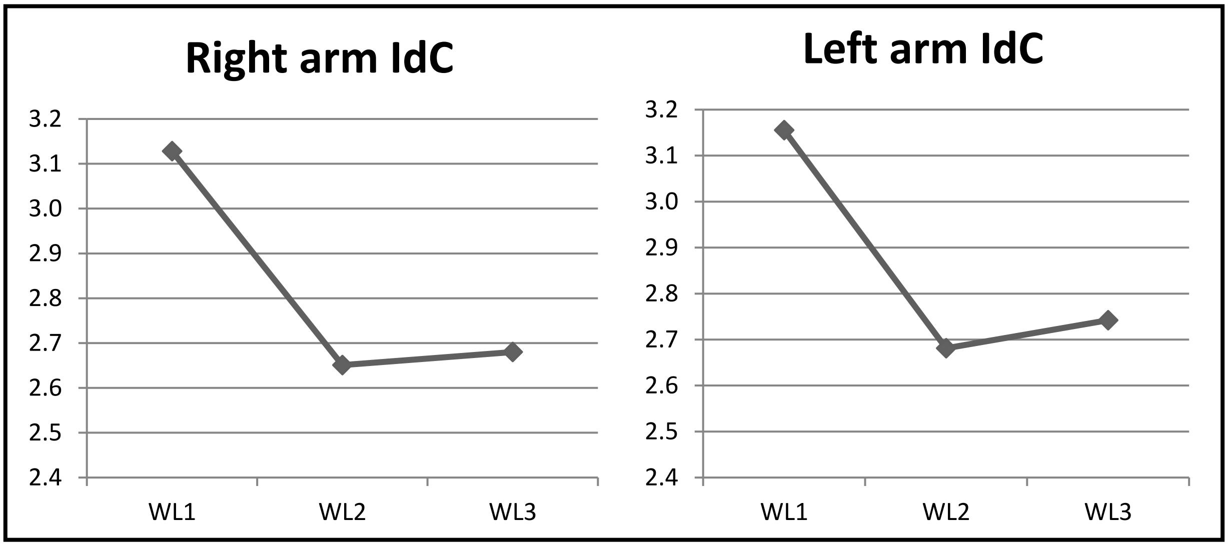

Figure 4-3. Index of Coordination (IdC) during the even loading profile for the right arm and the left arm. There were three workload trials corresponding to 50% of the workload at VO_{2Peak} (WL1), a workload corresponding to 65% of the workload at VO_{2Peak} (WL2), and a workload corresponding to 80% of the workload at VO_{2Peak} (WL3).

Two-way repeated measures ANOVAs were used to compare the IdCs for both the right arm and left arm. The IdCs were compared between the three workload trials (WL1, WL2 and WL3) and the three arm loading profiles (EL, RL and LL). For the right arm IdC, there was no significant interaction between the workload trials and the arm loading profiles (p = 0.257). There were no significant main effects for either the workload trials (p = 0.597) or the arm loading profiles (p = 0.990) (Figure 4-4). For the left arm IdC, there was no significant interaction between the workload trials and the arm loading profiles (p = 0.219). There were no significant main effects for either the workload trials (p = 0.628) or the arm loading profiles (p =

0.983) (Figure 4-5). Paired t-tests between the right arm and left arm showed no significant differences in the IdC between the arms under any condition ($p > 0.05$).

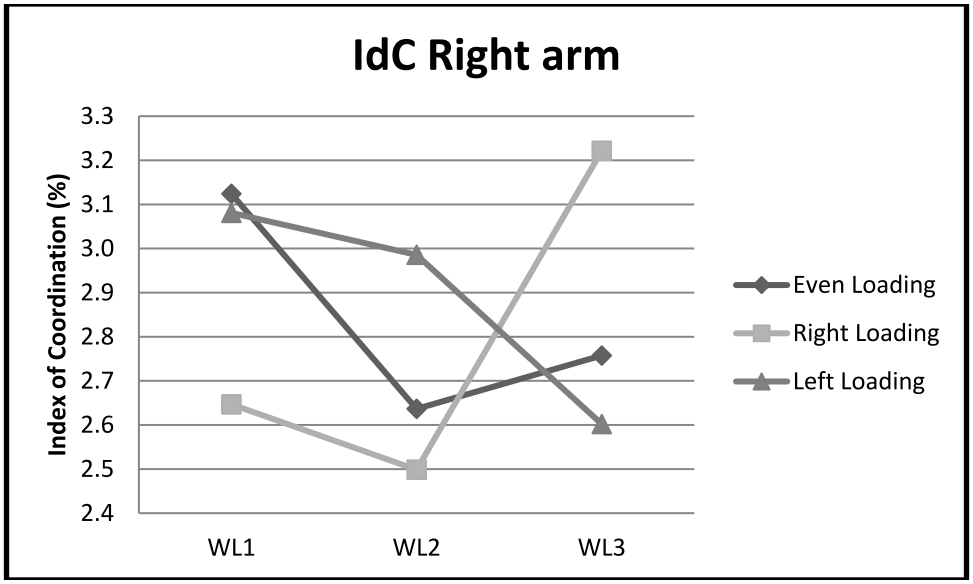

Figure 4-4. Index of Coordination (IdC) during arm coordination trials for the right arm. Each arm loading profile consisted of a workload corresponding to 50% of the workload at VO_{2Peak} (WL1), a workload corresponding to 65% of the workload at VO_{2Peak} (WL2), and a workload corresponding to 80% of the workload at VO_{2Peak} (WL3).

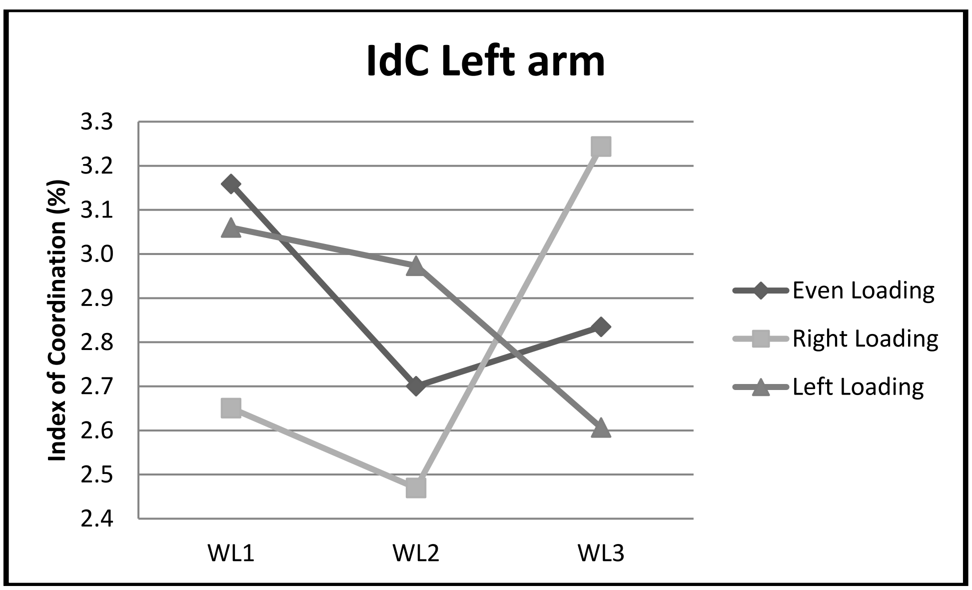

Figure 4-5. Index of Coordination (IdC) during arm coordination trials for the left arm. Each arm loading profile consisted of a workload corresponding to 50% of the workload at VO_{2Peak} (WL1), a workload corresponding to 65% of the workload at VO_{2Peak} (WL2), and a workload corresponding to 80% of the workload at VO_{2Peak} (WL3).

A two-way repeated measures ANOVA was used to compare the amount of work performed by both arms. There was no significant interaction between the workloads trials (WL1, WL2, WL3) and the three loading profiles (EL, RL, LL) ($p = 0.513$). There was a significant main effect for the workload ($p < 0.001$). A Bonferroni post hoc test showed significant differences between WL1 and WL2 ($p < 0.001$), WL1 and WL3 ($p < 0.001$), and WL2 and WL3 ($p < 0.001$). There was no significant main effect for the arm loading profile ($p = 0.141$) (Figure 4-6).

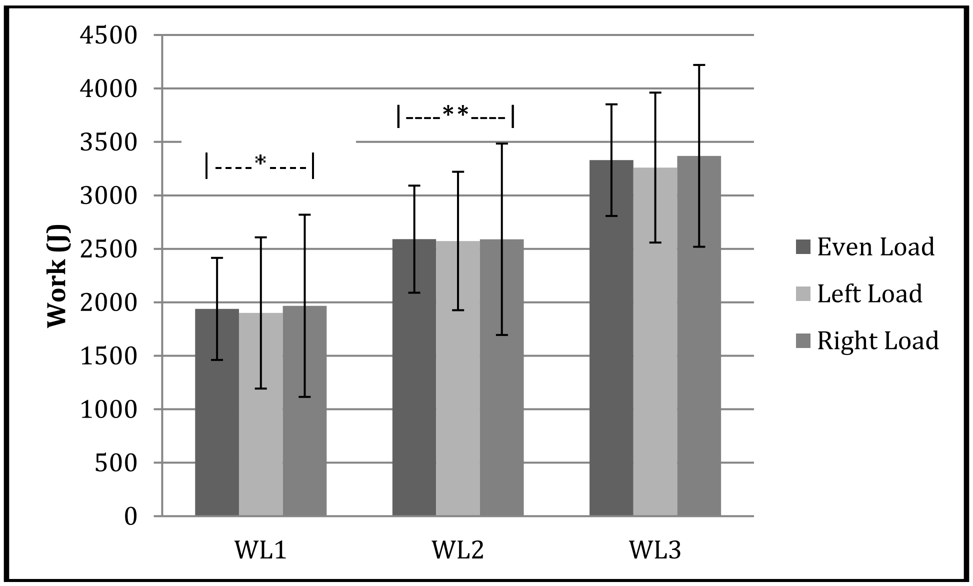

Figure 4-6. Total work performed by both arms during the arm coordination trial. Each trial consisted of a workload corresponding to 50% of the workload at VO_{2Peak} (WL1), a workload corresponding to 65% of the workload at VO_{2Peak} (WL2), and a workload corresponding to 80% of the workload at VO_{2Peak} (WL3).
* Significantly different from WL2 & WL3 ($p < 0.05$)
** Significantly different from WL1 & WL3 ($p < 0.05$)

When accounting for VO_2, there was no significant interaction between the workload trials (WL1, WL2, WL3) and the three loading profiles (EL, RL, LL) ($p = 0.961$). There was a significant main effect for the workload ($p < 0.001$). A Bonferroni post hoc test showed a significant difference between WL1 and WL3 ($p < 0.001$). There were no significant differences between WL1 and WL2 (p = 0.071) or WL2 and WL3 (p = 0.055). There was no significant main effect for the arm loading profile (p = 0.238). (Figure 4-7).

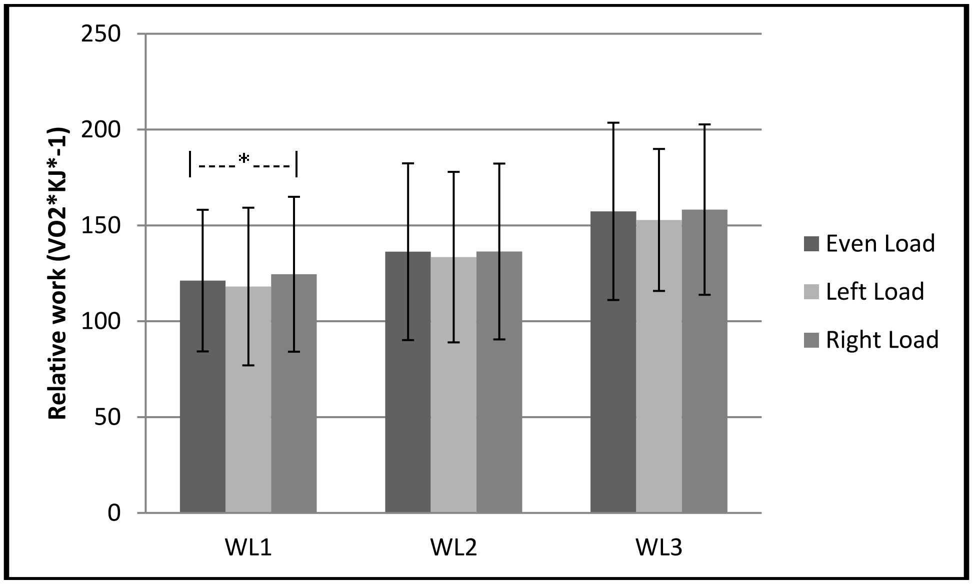

Figure 4-7. Relative work during arm coordination trials. Each trial consisted of a workload corresponding to 50% of the workload at VO_{2Peak} (WL1), a workload corresponding to 65% of the workload at VO_{2Peak} (WL2), and a workload corresponding to 80% of the workload at VO_{2Peak} (WL3).
* Significantly different from WL3 ($p < 0.05$)

To compare the work performed by each arm, a paired t-test was used with significance set at p = 0.05. With the exception of the EL at WL3, the work performed by the right arm was significantly different from the work performed by the left arm (Figure 4-8 and Figure 4-9).

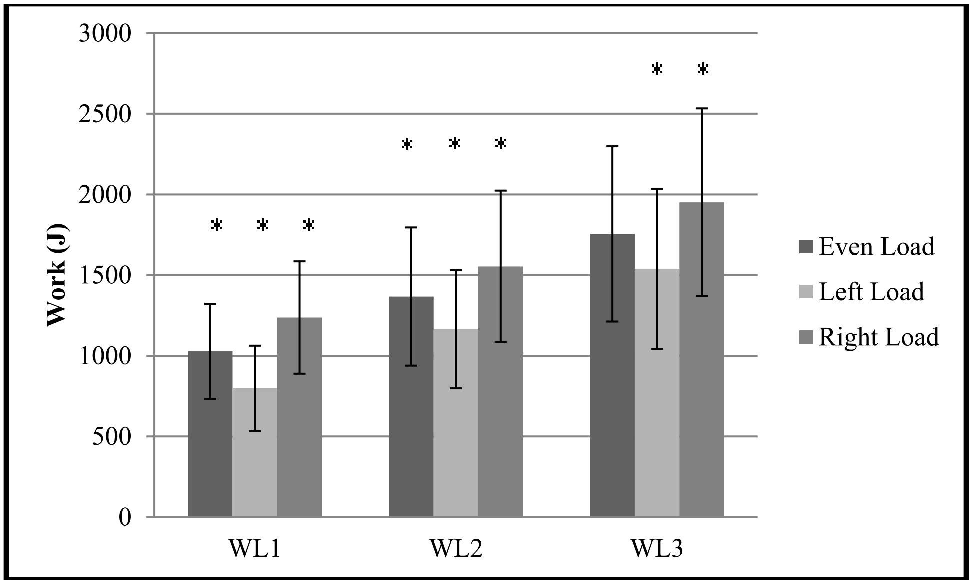

Figure 4-8. Total work performed by the right arm during the arm coordination trial. Each trial consisted of a workload corresponding to 50% of the workload at VO_{2Peak} (WL1), a workload corresponding to 65% of the workload at VO_{2Peak} (WL2), and a workload corresponding to 80% of the workload at VO_{2Peak} (WL3).
* Significantly different from left arm ($p < 0.05$)

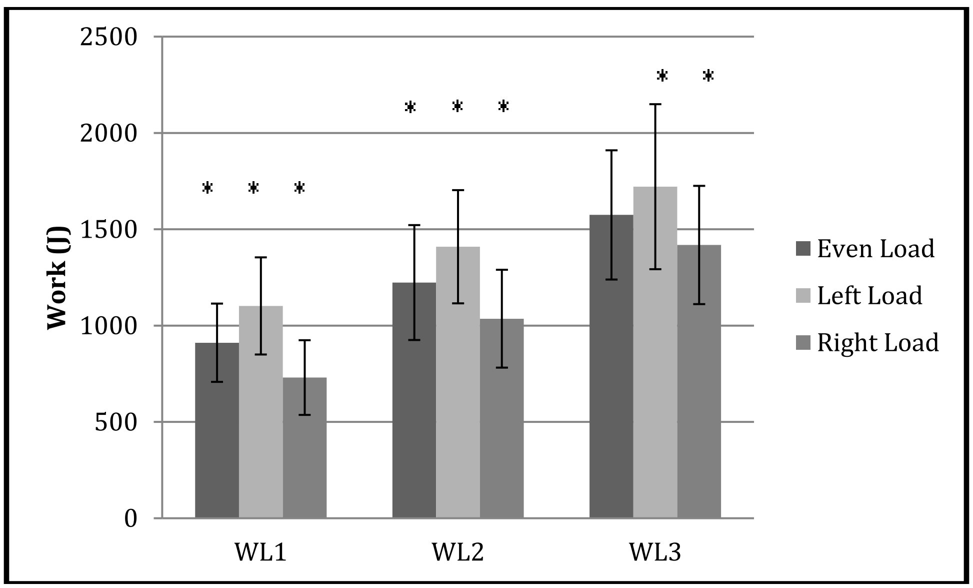

Figure 4-9. Total work performed by the left arm during the arm coordination trial. Each trial consisted of a workload corresponding to 50% of the workload at VO_{2Peak} (WL1), a workload corresponding to 65% of the workload at VO_{2Peak} (WL2), and a workload corresponding to 80% of the workload at VO_{2Peak} (WL3).
* Significantly different from right arm ($p < 0.05$)

Two-way repeated measures ANOVAs were used to compare the stroke length (SL) for each arm during the three workload trials (WL1, WL2, WL3) with the three arm loading profiles

(EL, RL, LL). For the right arm SL, there was not a significant interaction between the workload trials and the three arm loading profiles ($p = 0.919$). There were no significant main effects for the workload trial ($p = 0.167$) or the arm loading profile ($p = 0.646$). For the left arm SL, there was not a significant interaction between the workload trials and the three arm loading profiles ($p = 0.839$). There was a significant main effect for the workload trial ($p = 0.025$); however, a Bonferroni post hoc test did not detect a significant difference between workloads ($p > 0.05$).

A paired t-test was used and showed the SL of the right arm was significantly greater than that of the left arm during the LL at WL2 ($p = 0.025$) and the LL at WL3 ($p = 0.046$). The rest of the SLs were not significantly different between the right and left arms ($p > 0.05$) (Figure 4-10 and Figure 4-11).

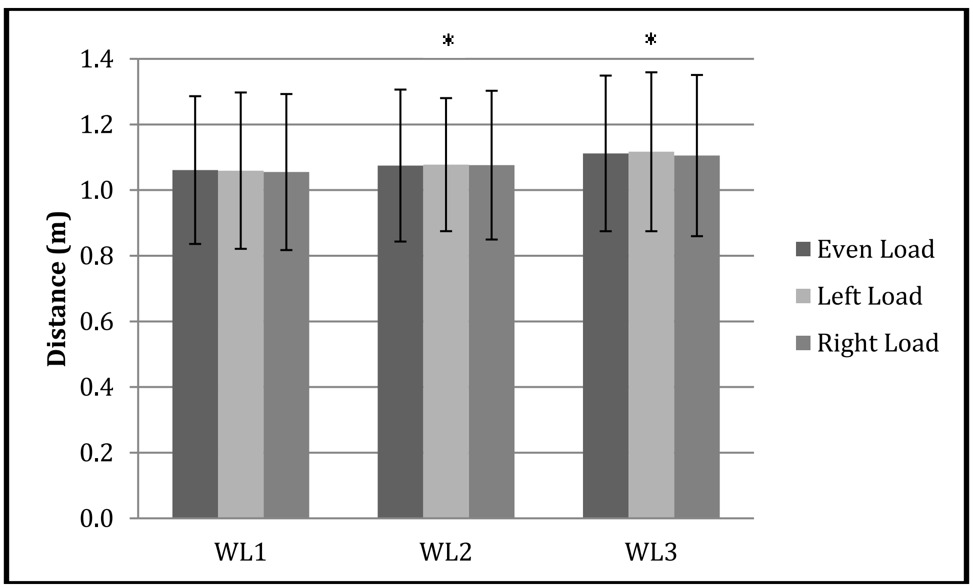

Figure 4-10. Right arm stroke length (SL) during the arm coordination trial. Each trial consisted of a workload corresponding to 50% of the workload at VO_{2Peak} (WL1), a workload corresponding to 65% of the workload at VO_{2Peak} (WL2), and a workload corresponding to 80% of the workload at VO_{2Peak} (WL3).
* Significantly different from left arm ($p < 0.05$)

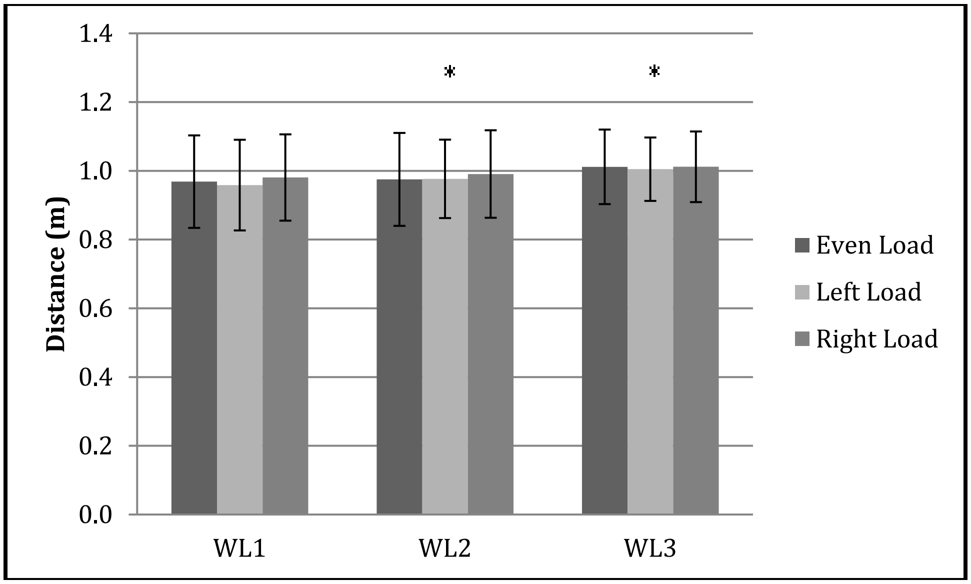

Figure 4-11. Left arm stroke length (SL) during the arm coordination trial. Each trial consisted of a workload corresponding to 50% of the workload at VO_{2Peak} (WL1), a workload corresponding to 65% of the workload at VO_{2Peak} (WL2), and a workload corresponding to 80% of the workload at VO_{2Peak} (WL3).
* Significantly different from right arm ($p < 0.05$)

CHAPTER 5

DISCUSSION

This study examined imbalances in the load distributed between two arms and the resulting impact on the metabolic demand of a rhythmic movement. This study was the first to use a swim bench to examine coordination dynamics during a rhythmic movement. Neither arm coordination, as detected by the index of coordination (IdC), nor the metabolic cost of arm work is affected by uneven arm loading. The change in the mean oxygen consumption (VO_2) of the group was minimal within each trial. Changes were also inconsistent from one workload to another. Some subjects increased their VO_2 between the even loading profile (EL) and either the right arm loading profile (RL) or the left arm loading profile (LL). During the next workload, the same subjects then decreased their VO_2 from the EL to either the RL or the LL (Figure 5-1, Figure 5-2).

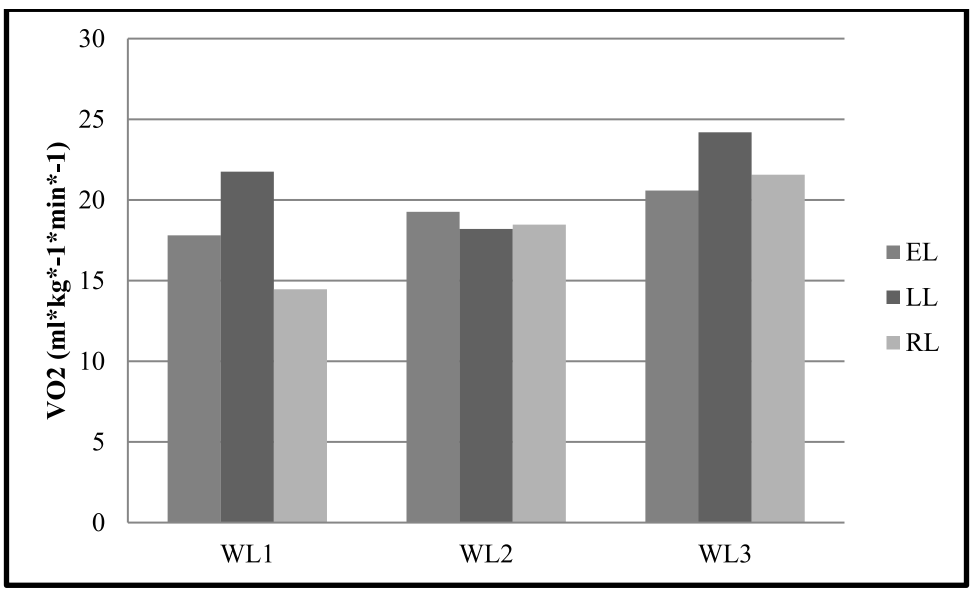

Figure 5-1. Oxygen consumption (VO_2) during arm coordination trials of one subject. Each trial consisted of a workload corresponding to 50% of workload at VO_{2Peak} (WL1), a workload corresponding 65% of workload at VO_{2Peak} (WL2), and a workload corresponding 80% of workload at VO_{2Peak} (WL3).

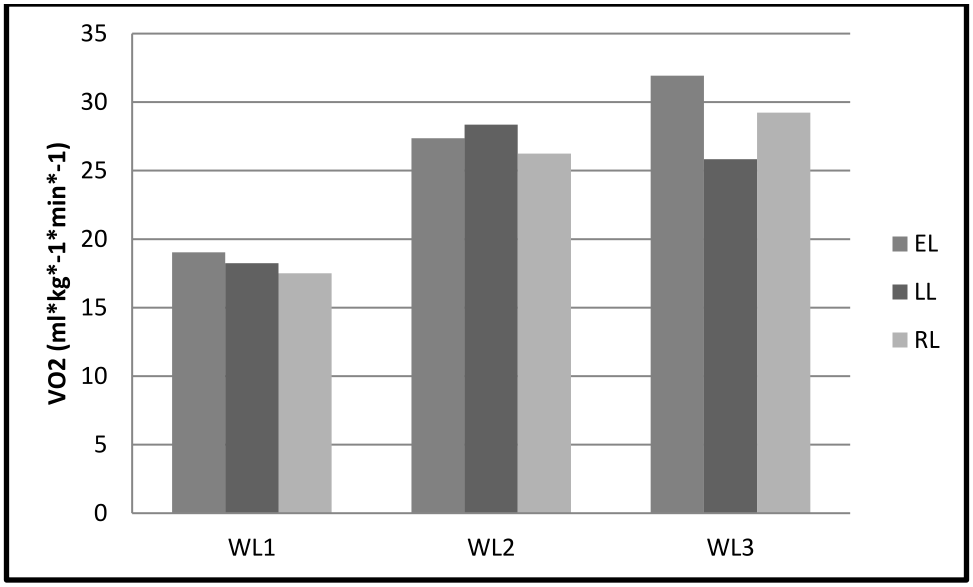

Figure 5-2. Oxygen consumption (VO_2) during arm coordination trials of one subject. Each trial consisted of a workload corresponding to 50% of workload at VO_{2Peak} (WL1), a workload corresponding 65% of workload at VO_{2Peak} (WL2), and a workload corresponding 80% of workload at VO_{2Peak} (WL3).

The stroke lengths (SL) of the left and right arms during the arm coordination trials (AT) were significantly different under the left loading profile at 65% of the workload at VO_{2Peak} (WL1) and 80% of the workload at VO_{2Peak} (WL2). Although the stroke lengths were different only under the left loading profile, there was no correlation with handedness or the side the subject breathes to during normal lap swimming. Furthermore, this change did not have an effect on either VO_2 or the IdC. A constant coordination pattern has been shown in a previous swim study that controlled for the swim speed throughout the different distances tested (Schnitzler, Seifert, & Chollet, 2009). Swimmers maintained a constant stroke rate (SR) throughout distances that progressively increased from 100 m to 400 m. The IdC remained negative throughout the trials without an increase in IdC as the length of the swim bout decreased, which had been found in other studies (Millet, Chollet, Chalies, & Chatard, 2002; Schnitzler, et al., 2008; Seifert, et al., 2007; Tourny-Chollet, et al., 2009). These other swim studies did not control the speed of the swim, which resulted in a transition towards a superposition coordination pattern as the distance swum decreased. This transition is suggested to allow the swimmers, especially elite swimmers, to produce greater propulsive forces through the combination of lengthening the propulsive phase and decreasing the recovery phase.

There were a few factors that might have contributed to a given IdC being preserved in the present study. First, the stroke rate (SR) of each subject was held constant throughout the AT. The SR was controlled to keep the work performed consistent throughout the workload profiles; this strategy proved effective as there were no significant differences within each workload profile of the study. By locking the SR, the subjects were limited in the number of adjustments they could make in either the propulsive or non-propulsive phases of the stroke. Therefore, this could have forced the subjects into one coordination pattern and could be one explanation to why the IdC did not change under an uneven loading profile. This is supported by similar results obtained in a previous study by Schnitzler et al. where swim speed was controlled in the water (Schnitzler, et al., 2008). The swim speed was set at a 400 m pace, and SR was held constant throughout the study. The coordination pattern that was used for the 400 m pace provided stability. Even though the swim distance was progressively increased throughout the study, the pace and coordination pattern remained the same. A change in the IdC would have been expected if the swimmer was allowed to determine the pace based upon the length of the swim bout. Furthermore, a change in the IdC would have altered the stability of the movement by making it less economical. The exercise bouts of the trials in the current study were all performed at a constant pace, similar to the 400 m pace used in Schitzler et al.'s study. However, the distribution of the workload was altered in the current study to examine the effects of coordination. In another earlier study, Russell et al. (2010) lessened the effects of an imposed rate for subjects walking on a treadmill by cueing only one body limb. The subjects walked on a treadmill with 0 kg, 3 kg, or 6 kg applied to either ankle. During one trial, the subjects were instructed to match their right heel strike with the sound of the metronome but were free to alter the coordination between two consecutive right leg steps. Although the changes in stride period for the right leg were small in the non-metronome condition, the slope of the change in stride period as the asymmetry increased was similar for both conditions (Russell, et al., 2010). For the current study, subjects could make adjustments to either the propulsion phase or the non-propulsion phase; however, the constraint of maintaining a given stroke rate may have hindered their selection of an optimal coordination pattern.

Second, it is possible that the coordination pattern on a swim bench is not identical to the coordination pattern in the water. In previous studies that have used IdC to characterize the arm coordination of swimmers, measurements were taken to calculate the propulsive and non-propulsive phases while the subjects swam in water (Schnitzler, et al., 2009; Schnitzler, et al., 2008; Tourny-Chollet, et al., 2009). Even though the swimming motion on a swim bench has been determined to accurately mimic the swimming motion in water (Armstrong & Davies, 1981), the two are still not identical. The swim bench does not allow for body rotation which could alter the motion to the point of affecting the coordination pattern. In the current study, subjects were allowed to choose their SR prior to the peak aerobic capacity test (PT). The mean SR for the group was 65 strokes*min^{-1}. This mean was in between the SRs that were imposed on subjects during PT on a swim bench in the study by Meerloo et al. (1987). However, while examining the typical SR most swimmers use in the pool, these SRs observed on a swim bench are at a considerably higher rate. Studies that have examined the SR of swimmers during different swimming bout lengths are presented below (Table 5-1). The current study consisted of 5-minute exercise bouts, which would be comparable to a 400 m swim bout in the water based on time. The mean SR utilized during a 400 m swim in previous studies was 39 strokes*min^{-1} (Craig & Pendergast, 1979; Schnitzler, et al., 2009; Schnitzler, et al., 2008; Seifert, et al., 2004). The increased SR on a swim bench could be due in part to assistance during the non-propulsive phase (NPP). When the arms recover on a swim bench, the weight attached to the hand paddles will provide some assistance in the motion. The degree of assistance provided has not been quantified, but it could potentially reduce the time spent in the NPP leading to an increase in the preferred SR of the subjects on a swim bench. Another possible explanation for the increased SR on the swim bench is the elimination of passive drag on the subject. While on the swim bench, the subject does not have to counter the drag that is placed on him due to the water. This lack of resistance could allow the swimmer to increase his SR.

	SR			SL		
Author	100 m	200 m	400 m	100 m	200 m	400 m
Craig et al., 1979	57 ± 1.0	46 ± 0.9	44 ± 1.1	2.03 ± 0.03	2.27 ± 0.4	2.28 ± 0.6
Schnitzler et al., 2008	45.0 ± 3.5	39.8 ± 6.8	39.2 ± 3.7	2.33 ± 0.22	2.31 ± 0.30	2.47 ± 0.2
Seifert et al., 2004	46.3 ± 2.9	41.3 ± 4.0	36.6 ± 3.6	2.34 ± 0.16	2.51 ± 0.20	2.66 ± 0.27
Schnitzler et al., 2008	35	35	37	2.12 ± 0.24	2.11 ± 0.22	2.04 ± 0.19

Table 5-1. Mean stroke rates (SR) and stroke length (SL) of competitive swimmers within the literature. SR presented in stroke*min^{-1} and SL presented in meters. A mean ± standard deviation for each distance was determined to compare with the current study.

Third, while analyzing the IdC of the subjects, two distinct groups appeared: a superposition group (IdC > 0) and a catch-up group (IdC < 0) (Figure 5-3 and Figure 5-4). Previous studies that have used the IdC to characterize the arm coordination of swimmers have reported uniform coordination patterns in their subjects (Schnitzler, et al., 2009; Schnitzler, et al., 2008; Tourny-Chollet, et al., 2009). As previously mentioned, these studies were all done with the subjects swimming in water. It is possible that the variables mentioned previously for increasing the SR during the test could have had similar effects on the IdC. Furthermore, the current study did not control for the type of swimmer (sprint, mid-distance, distance); however, there was no correlation between the swimmer type and IdC ($p > 0.05$).

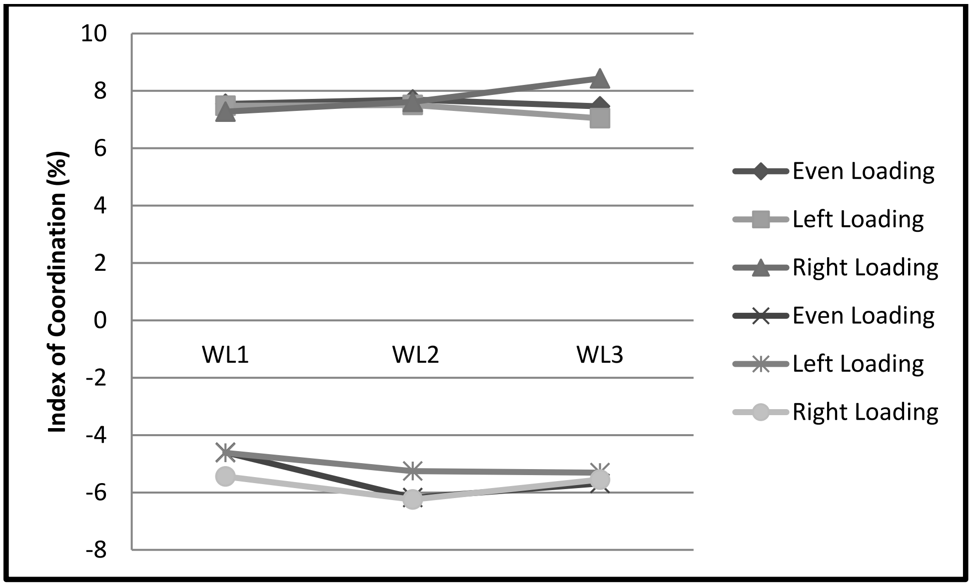

Figure 5-3. Right arm coordination of subjects using either a superposition or a catch-up pattern. Each trial consisted of a workload corresponding to 50% of workload at VO_{2Peak} (WL1), a workload corresponding 65% of workload at VO_{2Peak} (WL2), and a workload corresponding 80% of workload at VO_{2Peak} (WL3). A positive index of coordination (IdC) indicates a superposition pattern (n=7) while a negative IdC indicates a catch-up pattern (n=4).

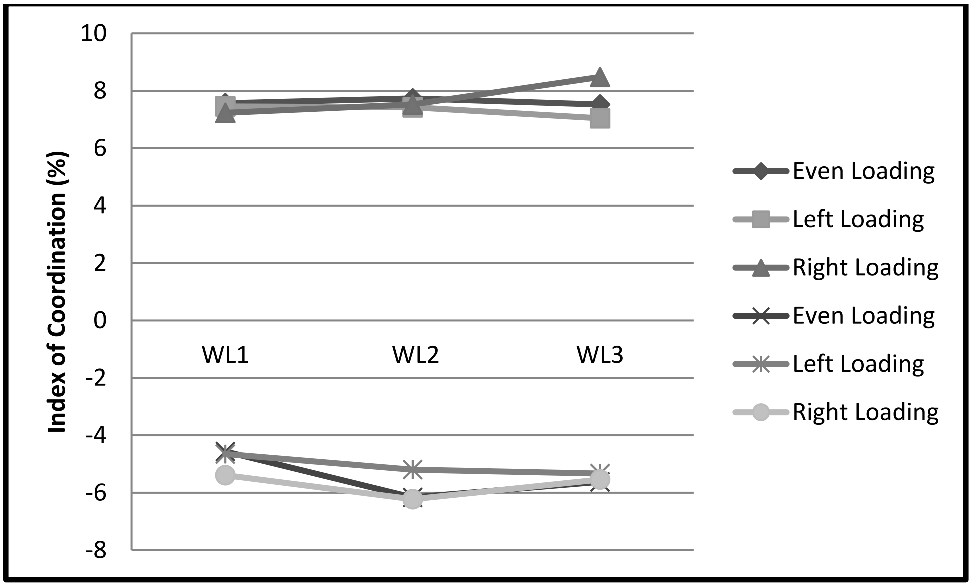

Figure 5-4. Left arm coordination of subjects using either a superposition or a catch-up pattern. Each trial consisted of a workload corresponding to 50% of workload at VO_{2Peak} (WL1), a workload corresponding 65% of workload at VO_{2Peak} (WL2), and a workload corresponding 80% of workload at VO_{2Peak} (WL3). A positive index of coordination (IdC) indicates a superposition pattern (n=7) while a negative IdC indicates a catch-up pattern (n=4).

Although the results from the peak aerobic capacity test (PT) were lower than what is expected from a standard maximal aerobic capacity test performed on a treadmill, the VO_2, respiratory exchange ratio (RER), and heart rate (HR) from the current study are comparable to previous results using a similar protocol (Meerloo, Collis, & Wenger, 1987). The lower VO_2 from swim bench protocols is due to fewer muscle groups being employed in the exercise bout. It has been suggested that a PT on a swim bench will result in an approximately 33% reduction in the VO_{2Max} (Armstrong & Davies, 1981). The PT in the current study unexpectedly resulted in the elimination of four subjects. While these four subjects' VO_2 and work performed increased with each stage of the PT, the subjects ended the test without the workload reaching a level that would allow for them to exercise at 50% of the workload during the initial stage of the AT. Two of the subjects could not continue past the fourth stage of the PT due to muscular fatigue. This was a problem because in order to create the different loading profiles for the left and right arms, subjects needed to complete enough stages in the PT such that WL1 could be produced. Although the other two subjects were able to complete stages past the fourth stage, the calculated workload at WL1 was still impossible to produce as it would have required a negative load.

Conclusions

This study was the first to use a swim bench to examine coordination dynamics. Arm coordination was examined on swimmers out of the water by modifying the workload placed on each arm. The results from the study suggest that the uneven load profiles did not affect either the coordination of the arms while on the swim bench or the metabolic demand of the movement. Even though the arms pulled uneven loads, the coordination and SL of each arm was unchanged throughout the rhythmic movement. Moreover, there were no changes in VO_2 within trials although the VO_2 of the subjects consistently increased between trials. The uneven load did not have any effect on the IdC of the subjects. Since the currents study's design was modeled after a treadmill study by Russell et al. (2010), the coordination results from the current study were expected to support Russell et al.'s findings. Instead, the results from the current study were similar to studies by Donker et al. (2002, 2005) where subjects walked on a treadmill and there was no transition in their coordination pattern.

Recommendations

To further investigate the coordination dynamics on a swim bench, additional research is needed to determine if swimmers' coordination patterns on the swim bench are similar to the coordination patterns they use while swimming in water. A comparison of self-selected coordination patterns of subjects on a swim bench and swimming in water would provide more information on the effects of a swim bench on swimming mechanics. Additional research is also needed to determine if "un-locking" SR would result in subjects changing the observed coordination patterns on a swim bench. Enforcing a selected pace has been shown to lead swimmers to sustain a given coordination pattern. Although the lengths of the exercise bouts in the current study were held constant, perturbing the limb was expected to have an impact on coordination. This result was shown by Russell et al.; however, that study enforced a pace by having the subjects match a metronome tempo based on only one limb (Russell, et al., 2010).

The current study could be repeated with the exception that subjects would be allowed to alter their stroke rate throughout the loading conditions. Allowing the freedom to select a pace could possibly allow the subject to produce the movement in a more metabolically economical manner since it would reduce the attention needed to maintain a certain pace. Furthermore, it would permit the exploration of different coordination patterns to optimize the metabolic cost within each loading condition.

APPENDIX A

Informed Consent Statement

INDIANA UNIVERSITY BLOOMINGTON INSTITUTIONAL REVIEW BOARD (IRB) REVIEW

DOCUMENTATION OF REVIEW AND APPROVAL (DRA)

IRB STUDY NUMBER: 1005001342
(IRB Office will assign)

SECTION I: INVESTIGATOR INFORMATION

Principal Investigator: **Hinman, Matthew, G.** **Department:** **Kinesiology**
(Last, First, Middle Initial------must have faculty/staff status or faculty sponsor must sign)

Building/Room No.: HPER/104 Phone: 812-856-7164 E-Mail: mghinman@indiana.edu

Contact Information:

Name: Joel M. Stager) Address: HPER 111 Phone: 855-1637

Fax: E-Mail: stagerj@indiana.edu

STUDENT PROTOCOLS ONLY: Name of the Student: Phone:

E-Mail:

Protocol Title: **Uneven Arm Load and Rhythmic Arm Coordination**

Sponsor/Funding Agency: PI on Grant:

Sponsor Protocol #/Grant #: Project Duration: From: -

Sponsor Type: ☐ Federal; ☐ State; ☐ Industry*; ☐ Not-for-Profit; ☐ Unfunded; ☐ Internally Funded

Grant Title (if different from project title):

SECTION II: TYPE OF REVIEW

☐ Expedited Review
☒ Full Board Review

SECTION III: SPECIAL SUBJECT POPULATIONS INVOLVED IN THE RESEARCH

☐ Children
☐ Cognitively Impaired
☐ Economically/ Educationally Disadvantaged
☐ Human Fetuses (or Fetal Tissue) or Neonates
☐ Pregnant Women
☐ Prisoners

SECTION IV: DOCUMENTS INCLUDED WITH RESEARCH SUBMISSION

☒ Informed Consent Document(s), dated:
# of consent document(s):
☒ Summary Safeguard Statement (SSS), dated:
☐ Authorization(s), dated:
☒ Protocol, dated:
☐ Other, description:

☐ Assent Document(s), dated:
# of assent document(s):
☒ Recruitment Materials, dated:
☐ Advertisement(s), dated:
☒ Surveys, Questionnaires, dated:

You only need to list document dates if they are required by the investigator or sponsor.

SECTION V: INVESTIGATOR STATEMENT OF COMPLIANCE

By submitting this form, I assure the Board that all procedures performed under the project will be conducted in strict accordance with those federal regulations, Indiana University policies that govern research involving human subjects. I acknowledge that I have the resources required to conduct research in a way that will protect the rights and welfare of participants. I agree to submit *any* deviation from the project (e.g. change in principal investigator, research methodology, subject recruitment procedures, etc.) to the Board in the form of an amendment for IRB approval prior to implementation.

Signature of Investigator: received by email Date: May 28, 2010

SECTION VI: IRB APPROVAL

This research project, including all documents included with the submission (e.g., informed consent statement, authorization, and/or waiver of authorization) has been reviewed and approved by the Indiana University Bloomington Institutional Review Board for a maximum of a one year period beyond the final approval date unless otherwise indicated as follows:________________________

Authorized IRB Signature:__[redacted]____________________IRB Approval Date:__Jul. 15, 2010______

Recorded in the Minutes of: ________________

IRB Study # 1005001342

INDIANA UNIVERSITY BLOOMINGTON

INFORMED CONSENT STATEMENT

Uneven Arm Load and Rhythmic Arm Coordination

You are invited to participate in a research study of arm coordination effect on the metabolic demand of movement. You were selected as a possible subject because you are a swimmer at Indiana University – Bloomington. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

The study is being conducted by Matthew G. Hinman of the Department of Kinesiology at the HPER at IU. It is not funded by any agency and is being conducted under the supervision of Dr. Joel M. Stager in the Department of Kinesiology at Indiana University Bloomington.

STUDY PURPOSE

This research will be conducted to investigate the energy response of arm coordination to a change in the amount of work performed. This is important to better understand the impact of bilateral coordination (two arm) by the central nervous system through adjustments in movement to fine tune energy cost for doing work or exercise.

NUMBER OF PEOPLE TAKING PART IN THE STUDY:

If you agree to participate, you will be one of 30 subjects who will be participating in this research.

PROCEDURES FOR THE STUDY:

If you agree to be in the study, you will do the following things:

You will be asked to complete two 120 minute testing sessions separated by 7 days. You will be asked to come to both testing sessions following a four hour fast where you will only have consumed water. All testing will be held in the Human Performance Lab 080 in the HPER building at Indiana University-Bloomington. Prior to the testing session, you will complete a modified Physical Activity Readiness Questionnaire (PAR-Q) to determine if you are able to complete an exercise bout and a swimming history questionnaire. All testing will occur in a private room. If you do not qualify for the study based on the PAR-Q or your swimming performance, both your PAR-Q and swimming history questionnaire will be destroyed at the completion of the study.

Anthropometry

Your height will be measured using a meter stick attached to a wall (stadiometer). You will be asked to place your feet, heels, back and buttocks against the wall. A board will be placed on the top of your head and the researcher will record the height from the stadiometer. A digital scale will be used to measure your weight. The scale will be zeroed and you will be instructed to sit on a stool which is located on the scale. The weight will then be recorded by the researcher. Once height and weight are recorded, you will be instructed to place a heart rate monitor around your chest. The heart rate monitor needs to be placed against your skin, so you will be allowed to use a restroom/locker room to attach the monitor. You will then be asked to complete a maximal test on a Swim Bench to determine your maximal aerobic capacity.

Familiarization Trial

Prior to the start of the maximal test and the arm coordination test, you will be allowed a five minute period to become familiar with the equipment. You will be instructed to lie on your stomach on a Swim Bench with your head extended beyond the bench supporting the chest and abdomen. This swim bench is similar to an incline bench where your upper body will be slightly elevated above your feet. A stool will be provided for supporting your legs. You will be attached to the swim bench with cloth/nylon straps attached around your thighs to keep you from moving on the swim bench. The straps will not hinder your breathing during the test because the straps will only attach you to the bench below your waist. This position mimics the position you would be in during front crawl swimming. You will remain in this position for all exercise bouts. While still on the swim bench you will be handed two hand paddles, which you will grasp one with each hand. Each paddle is attached to separate weight stacks. This allows for different loads to be attached to each paddle. You will then be asked to perform a front crawl swimming motion while pulling the weight stacks attached to each hand paddle. You will have a chance to try an even and two uneven weight loading profiles that will be tested during the trials. At the end of the familiarization trial, you will be instructed to perform three continuous strokes. These will be used to determine your typical stroke length.

Discontinuous Maximal Aerobic Capacity Exercise Test

This test measures maximal oxygen consumption capacity. You will be given an opportunity to warm up and familiarize yourself with the swim bench before the test begins. A rubber mouthpiece and nose clip is worn throughout the duration of the test. All rubber mouthpieces and nose clips are cleansed in a detergent solution and disinfected following each use. You will wear a heart rate monitor to measure heart rate which will be worn around your chest. You are free to stop the test at any time. In addition, the test will be terminated for any of the following conditions: (1) Volitional fatigue (you feel too tired to continue), (2) unable to maintain the required stroke rate, (3) no further increase in oxygen consumption with increased work load is noted, (4) you exceed your age predicted heart rate (220 – your age) by more than 10 beats, and (5) the respiratory quotient exceeds 1.10. If only conditions 1 or 2 are met, you will be asked if you can complete the next stage after a ten-minute rest period. If you agree, a ten-minute rest period will begin and you will start the exercise test at the end of the rest period. If you feel you can no longer continue even with the additional rest, the test will be terminated.

The aerobic capacity test will begin with five minutes of rest while you are lying quietly breathing through a mouthpiece and wearing a nose clip. At the end of the five-minute rest period, you will be given arm paddles to pull for 4 minutes at a stroke rate of approximately 60 strokes per minute and an arm load of about 2 lbs per arm. You will be instructed to complete a full stroke for each pull. A bell will ring when you have completed a full stroke. This distance will equal the normal stroke length that was measured during the familiarization trial. A 5-minute rest period will follow where you will rest on the swim bench. The arm load will then be increased by about half pound increments for each 4-minute exercise bout and 5-minute recovery until you can no longer continue or one of the 5 termination conditions occurs. The test should last about 120 minutes. You will then be asked to schedule another testing session the following week for the arm coordination tests. This test should last about 120 minutes.

Arm Coordination Trials

You will be asked to complete three trials with three conditions for each trial for a total of nine arm exercise bouts. Each condition will consist of a three 5-minute submaximal exercise bout to measure arm coordination and pulmonary/metabolic functions. You will be attached to the mouthpiece; your expired gases will be analyzed continuously using CO_2 and O_2 gas analyzers to measure the metabolic functions.

While lying on the swim bench, you will be handed two hand paddles, which you will grasp one with each hand. Each paddle is attached to separate weight stacks. This allows for different loads to be attached to each paddle. You will be instructed to pull the hand paddles in a swim stroke motion at a rate of approximately 60 strokes per minute. You will maintain this stroke rate with the assistance of a metronome, which will be placed under the swim bench such that you can hear the tone and see a light that will flash with each tone. You will be asked to initiate a pull at the sound of the metronome alternating pulling the paddles with the right and left arm with each beat. You will be instructed to complete a full stroke for each pull. A bell will ring when you have completed a full stroke. This distance will equal the normal stroke length that was measured during the familiarization trial. The amount of weight attached to each paddle will change for each of the three conditions, with two conditions requiring different loads be placed on each arm. The loads will be determined by load at a given percentage of your $VO_{2\ Peak}$ as determined in the maximal aerobic capacity test.

Heart rate will be recorded every thirty seconds throughout the condition. After each condition you will enter a 5-minute recovery period. Your blood pressure will be taken during the rest periods using your right arm. If your measurement is at or above 260/111 mmHg the test will be terminated. Following each trial, you will be allowed to remove the mouthpiece and nose piece and will be allowed a ten minute rest period where you can get off the swim bench. At the completion of the rest period, you will attach the mouthpiece and nose piece, and then enter the five next trial. The arm coordination testing will occur in one visit and will last about 120 minutes.

RISKS OF TAKING PART IN THE STUDY:

While on the study, the risks are:
The risks for submaximal exercise are:
There is minimal risk from performing exercise bouts at submaximal workloads. While performing the front crawl motion during the exercise bouts, you may feel muscle fatigue, cramping, muscle strain or soreness. For the apparently health adult, morbidity: 1/887,526 participant hours, mortality: 1/1,124,200 participant hours.

The risks for maximal exercise testing are:
The risks are similar to the minimal risks observed while competing in a swimming competition. A maximal exercise bout for healthy asymptomatic persons under the age of 40, as described by the American College of Sports Medicine, presents little or no risk (< 0.01% risk of death) to the subject and does not require medical clearance. However the possible discomforts involved with exercise testing can include episodes of transient lightheadedness, chest discomfort, arm cramps, significant arm fatigue, nausea, occasional irregular heartbeats, and abnormal blood pressure responses. The risk of heart attack during maximal exercise testing, although minor, (approximately 1 to 2 in 10,000) does exist.

The risks/discomforts for exercise in this prone position, tied to a bench are:
There are few risks and discomforts reported from experience swimmers exercising on a swim bench in this position. You may experience minor soreness on your chest from lying on their stomach during the exercise bouts.

There may be a greater blood pressure response to arm exercise as compared to leg exercise. However, for well conditioned, physically fit individuals, the additional risks are minimal.

To minimize muscular discomfort, stretching will be encouraged prior to the start of the study. A ten minute recovery period will occur between the second and third trial. Standardized testing procedures will be utilized to further minimize the risks associated with the procedures.

All rubber mouthpieces and nose clips are cleansed in a detergent solution and disinfected following each use.

Data will be coded to help preserve confidentiality. Data will be stored on computers in locked rooms and on password-protected computers. Paper will be stored in locked rooms.

BENEFITS OF TAKING PART IN THE STUDY:

The benefits of participation are similar to any benefits experienced during an exercise session.

ALTERNATIVES TO TAKING PART IN THE STUDY:

An alternative to participating in the study is to choose not to participate.

CONFIDENTIALITY

Efforts will be made to keep your personal information confidential. We cannot guarantee absolute confidentiality. Your personal information may be disclosed if required by law. Your identity will be held in confidence in reports in which the study may be published and in any databases in which results may be stored.

Organizations that may inspect and/or copy your research records for quality assurance and data analysis include groups such as the study investigator and his/her research associates, the IUB Institutional Review Board or its designees, and (as allowed by law) state or federal agencies, specifically the Office for Human Research Protections (OHRP) who may need to access your research records.

COSTS

No costs are expected for participation in this study.

PAYMENT

You will not receive payment for taking part in this study.

COMPENSATION FOR INJURY [For research studies that are greater than minimal risk]

In the event of physical injury resulting from your participation in this research, necessary medical treatment will be provided to you and billed as part of your medical expenses. Costs not covered by your health care insurer will be your responsibility. Also, it is your responsibility to determine the extent of your health care coverage. There is no program in place for other monetary compensation for such injuries. However, you are not giving up any legal rights or benefits to which you are otherwise entitled.

CONTACTS FOR QUESTIONS OR PROBLEMS

For questions about the study or a research-related injury, contact the researcher Matthew G. Hinman at 812-856-7160 or by email at mghinman@indiana.edu.

For questions about your rights as a research participant or to discuss problems, complaints or concerns about a research study, or to obtain information, or offer input, contact the IUB Human Subjects office, 530 E Kirkwood Ave, Carmichael Center, 203, Bloomington IN 47408, 812-856-4242 or by email at iub_hsc@indiana.edu

VOLUNTARY NATURE OF STUDY

Taking part in this study is voluntary. You may choose not to take part or may leave the study at any time. Leaving the study will not result in any penalty or loss of benefits to which you are entitled. Your decision whether or not to participate in this study will not affect your current or future relations with the investigator(s).

SUBJECT'S CONSENT

In consideration of all of the above, I give my consent to participate in this research study.

I will be given a copy of this informed consent document to keep for my records. I agree to take part in this study.

Printed Name of Subject:____

Signature of Subject:____**Date**:____________________

Printed Name of Person Obtaining Consent:__________________________________

Signature of Person Obtaining Consent:_____________________________________**Date**:____________________

Form date: June 28, 2010

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APPENDIX B

Curriculum Vitae

Matthew G. Hinman

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Education

INDIANA UNIVERSITY, School of HPER, Department of Kinesiology, M.S. May 2011

- Thesis: "Uneven Arm Load and Rhythmic Arm Coordination"
- Committee: Joel Stager Ph.D. (chair), Jeanne Johnston Ph.D., S. Lee Hong Ph.D., David Koceja Ph.D.
- Field of Study: Exercise Physiology

DEPAUW UNIVERSITY, School of Liberal Arts, Department of Kinesiology, B.A. 2007

Professional Experience

- INDIANA UNIVERSITY, Recreational Sports, Swim Instructor, September 2010-Present
  - Swim for Fitness

- INDIANA UNIVERSITY, Researcher, May 2009-Present
  - International College Health and Fitness
  - Step into Fitness for Faculty and Staff

- COUNSILMAN CENTER SWIM TEAM, Swim Coach, May 2008- December 2010
  - High school coach
  - Age group coach

- INDIANA UNIVERSITY, Research Assistant, August 2008- May 2009
  - Physical Activity of First Year College Students
  - Physical Activity and Technology of College Students

Research

- Focus of my research centers around physical activity.
- Studied oxygen consumption and arm coordination while on a modified swim bench as well as quantifying swimming distance using accelerometers.
- Actively participated in research pertaining to quantifying and categorizing physical activity as well as assessing cardiovascular risk factors within a college population.

Published Abstracts and Presentations

Johnston, J.D., Thosar, S., **Hinman, M.,** Amadeo, M., Arvin, C., Massey, A., Geary, C. (2011). Interdepartment Collaboration improves the delivery and outcome of a pedometer program within a community setting. *American Public Health Association 139th Annual Meeting & Expo,* Washington, D.C.: October 2011.

Hinman, M.G., Stager, J.M. (2011). Performed Work during a Discontinuous VO_{2max} Swim Bench Protocol. *American College of Sports Medicine Annual Meeting*, Denver, Colorado: June 2011.

Thosar, S.S., Johnston, J.D., **Hinman, M.G.,** Amadeo, M.L., Arvin, C.S., Geary, C.A. (2011). Impact of a Worksite Wellness Program on Physical Activity and Body Composition. *American College of Sports Medicine Annual Meeting*, Denver, Colorado: June 2011.

Johnston, J.D., Massey, A., Sheldon, L., Marker-Hoffman, R., **Hinman, M.** (2010). Impact of a game based intervention on physical activity within the college student population. *American Public Health Association 138th Annual Meeting & Expo,* Denver, Colorado: November 2010.

Wright, B.V., **Hinman, M.G.,** Stager, J.M. Accelerometery as a Means of Quantifying Training Distance and Speed in Competitive Swimmers. *Internatinoal Symposium on Biomechanics and Medicine in Swimming,* Oslo, Norway: June 2010.

Marker-Hoffman, R.L, **Hinman, M.G.,** Linderman, A.K., Johnston, J.D. Sex Differences in Pedometer-Determined Physical Activity within First Semester First Year College Students. *Medicine & Science in Sports & Exercise*. 2010, 40 (5): 612.

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Johnston, J.D., Linderman, A.K., Marker-Hoffman, R.L, **Hinman, M.G.** Body Composition And Cardiovascular Risk Factors Within College-aged Students. *Medicine & Science in Sports & Exercise*. 2009, 41(5):109.

Marker-Hoffman, R.L, Johnston, J.D., Linderman, A.K., **Hinman, M.G.** Self Reported Weight Category vs. Actual Weight Category Within College-aged Students. *Medicine & Science in Sports & Exercise*. 2009, 41(5):108.

Hinman, M.G., Wright B.V., Scofield E.W., Lundgren E.A., Stager J.M. Use of Accelerometers as a Means of Quantifying Swim Training Load. *Medicine & Science in Sports & Exercise*. 2008, 40(5):S382.

Grants

- Graduate Student Travel Grant-In-Aid Award. School of HPER, Indiana University. 2008.
- Graduate Student Travel Grant-In-Aid Award. School of HPER, Indiana University. 2009.
- Graduate Student Travel Grant-In-Aid Award. School of HPER, Indiana University. 2010.
- Graduate Student Travel Grant-In-Aid Award. School of HPER, Indiana University. 2011.

Professional Memberships

- American College of Sports Medicine - Member